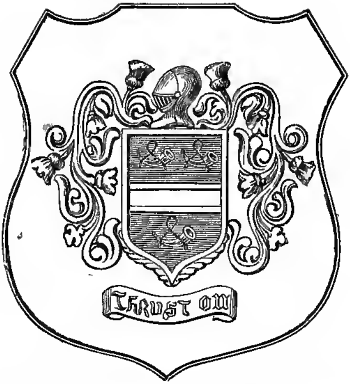
LESSONS

CHEMISTRY


THRUST ON

CHAMBERS'S EDUCATIONAL COURSE.

INORGANIC CHEMISTRY

BY THE LATE

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With New Notation added.

W. & R. CHAMBERS
LONDON AND EDINBURGH

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Edinburgh:
Printed by W. and R. Chambers.

PREFACE TO THE FIRST EDITION.

BY THE LATE PROFESSOR GEORGE WILSON.

So many excellent text-books on Chemistry have been published within the last few years, that some apology seems necessary for the issue of another. It may be found in the fact that, admirable as are the extant treatises on the science, they are too extensive in their aim, too bulky, and too costly, for a large class of students who are anxious to acquire some knowledge of a branch of learning of which few can at the present day afford to be altogether ignorant.

The want of such a work has been felt so strongly by many, that the publishers of this volume have seen the necessity of meeting it in connection with their Educational Course, and, in compliance with their request, I have prepared the following Treatise.

Its object is strictly elementary; its purpose being to introduce the student to a knowledge of the more important fundamental laws of Chemistry, and to make him familiar with the properties of the chief elementary substances and their more remarkable compounds. In conformity with this aim, much greater space has been devoted to the discussion of such subjects as the General Properties of Matter, Weight, Chemical Affinity, the Laws of Combining Proportion, the Atomic Theory, Chemical Nomenclature, Chemical Notation, &c. than has been customary in works of the kind.

PREFACE TO THE THIRD EDITION.

THE recent advances in Chemistry, especially in relation to the changes in the atomic weights or combining proportions of elementary substances, and the symbolic representation of compounds, have rendered it necessary to make corrections and additions on every part of this treatise. So many alterations have been made in the nomenclature and notation of chemical substances, that it will be found perplexing to read the present work side by side with either of the previous editions; but for the sake of aiding former students in understanding the relations of the more commonly occurring compounds, the names and symbols of such by the older notation are given within brackets where it has appeared desirable to do so. The symbols occurring throughout the treatise, and *not included within brackets*, are entirely on the new notation—viz., that originally suggested by Gerhardt, and now accepted and employed by the majority of British chemists. The beginner in Chemistry is therefore advised to restrict himself to the new notation alone. The present edition contains chapters on the atomicity of the elements, the classification of substances according to atomicity, and the theory of the constitution of acids, bases, and salts. There is likewise a series of tables relating to specific gravity, strengths of solutions, thermometric scales, &c., which will be found useful to the cultivator of the science.

The series of exercises placed at the end of the book cannot assume too much importance, and the pupil ought systematically to study and work out the answers to each set of exercises as he proceeds through the treatise.

STEVENSON MACADAM, Ph.D.

The part containing ORGANIC CHEMISTRY is in course of preparation, and will be issued shortly; whilst the companion treatise on PRACTICAL CHEMISTRY is also undergoing revision according to the new nomenclature and notation, and will be through the press immediately. S. M.

October 1866.

DIRECTIONS FOR READING THIS TREATISE.

In using this work, the teacher or pupil is recommended to read the first twenty-seven pages with some care before proceeding further. The beginner must not expect to understand the introductory portions at once, but must go back from time to time to their study, when he will find them become more and more intelligible as he grows familiar with the properties of chemical substances explained in the later pages. On the other hand, some acquaintance with the contents of the preliminary chapters is essential to an intelligent study of the chemical elements, so that the earlier and the later chapters or sections must be studied alternately or together.

The Laws of Combining Proportion, and all that follows to the end of page 72, should be left unconsidered till the properties of oxygen, hydrogen, nitrogen, and their compounds, as detailed from page 73 to 120, have been studied, after which the laws of Combining Proportion and the Atomic Theory should be thoroughly learned.

A knowledge of Chemical Nomenclature and Notation cannot be too early acquired; but it will depend greatly on the age and capacity of the pupil, at what stage in his progress these subjects can best be introduced. This general direction, however, may be given: A portion of each lesson should be devoted to the study of the properties of the various elements and their compounds, with as full experimental illustration as circumstances permit, whilst another part of the lesson is devoted to such subjects as Chemical Nomenclature, &c.; or the lessons may be alternated—an hour, for example, being devoted on one day to experiment and the exposition of phenomena, and on another to the explanation of laws and theories. In this way one set of lessons would begin at page 73, with Inorganic Chemistry, and the other at page 1, with the general principles of the science, so as to introduce variety.

A single further remark seems called for. Greater importance is given to Chemical Notation in the following pages than in kindred elementary works, and the immense majority of the chemical changes discussed are illustrated by *symbols*. Their employment has been objected to by some, as needlessly perplexing beginners. In this work, however, as far as possible, every chemical change has been explained in words as well as by symbols, so that those who choose may disregard the latter. Nevertheless, it is not desirable that this should be done; students, instead of disliking, prefer symbols, and rapidly acquire familiarity with their use, especially if gradually habituated to their employment (see note, p. 63). In the present state of Chemistry, indeed, a student of the science is wronged if he is not made familiar with the chemical symbols, for they are employed by all chemists, and Chemistry, instead of being simplified, really becomes more perplexing if symbols are exchanged for words.

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INTRODUCTION.

1. It would be of great advantage to the beginner in Chemistry, if it were possible to give a simple but sufficient definition of the nature of the science, on the study of which he is about to enter, so that he might have some conception of the nature of the facts about which he is to be busied, and a certain preparatory acquaintance with the kind of knowledge with which chemistry deals.

2. Before, however, a single science can be properly defined, we must know not only it, but all other sciences perfectly, otherwise we may exclude from our definition something which it should have contained, or include something which in reality belongs to the definition of another science. As man, however, is not omniscient, he is unable to give perfect definitions of any of the sciences.

3. It is further to be remembered that the division of human knowledge into various branches, such as Chemistry, Natural Philosophy, Electricity, and the like, is to a great extent made, not because we can shew that a sharp line of demarcation separates each of these so-called sciences from all the rest, but because the limitation and feeble grasp of our faculties compel us to parcel out universal science, so as to restrict ourselves to

departments of it, small enough to be investigated during the comparatively short life of a single individual.

4. Waiving, then, any attempt at logical definition, we may nevertheless endeavour to convey by description an idea of the nature and object of chemistry, sufficient to enable the pupil to begin his studies profitably. The chemistry we are about to prosecute is that of the earth: our knowledge of the nature of the other heavenly bodies being far too slender and limited to permit their chemistry being discussed in this treatise. Our globe, then, to which we restrict ourselves, may be considered as divided like a great kingdom among the students of the physical sciences.

5. The astronomer, for example, explains the relations of the earth to the sun, the moon, and the other heavenly bodies, besides much else which we cannot stop to particularise. The geologist discusses the changes which have occurred on the greater masses of the globe since its creation, and dwells on the age, origin, and nature of rocks, fossils, volcanoes, mountains, valleys, rivers, seas, &c. The mineralogist, a kind of lesser geologist, breaks down the great rocky masses into their smaller constituents, and points out the ores, spars, and crystals, which, by their union, form hills and mountains. The botanist unveils the forms, structures, and actions of dead and living plants; and the anatomist does the same in regard to animals.

6. The natural philosopher expounds the properties which belong to matter in its different physical conditions, such as liquidity, solidity, and the gaseous state; and explains the laws which determine the motion and rest, as well as many of the properties of solids, liquids, and gases, besides much more which cannot here be enlarged upon. When these philosophers have exhausted all the resources of their respective sciences in explaining the physical characters of our planet, there still remains, among others, one most important question undecided, which the chemist comes upon the field to answer.

7. The problem which the chemist solves, will be best

understood by putting a question to certain of the philosophers to whom we have referred. The geologist, then, is asked to explain why coal and marble are so different from each other: Does each of them consist of one substance, and both of the same, or are they made up of many unlike ingredients; and if so, what are they? The mineralogist is requested to account for the difference in properties exhibited by the diamond and the ruby, and to say whether each consists of one kind of matter, or of several unlike kinds.

8. A similar answer is required at the hands of the anatomist as to the cause of the difference in properties which distinguishes blood and milk from each other; and the natural philosopher, in like manner, is applied to, to determine whether water and oil are in nature, essence, or composition, in all respects identical, or differ totally as regards their component ingredients. To these questions no answers could be returned by any of the sciences to which we have referred. All of them would reply that it lay beyond the resources of their knowledge to furnish a solution of the problem.

9. The science which solves the problem is chemistry, and the chemist may be represented as effecting its solution somewhat thus: He begins, as it were, by asking himself the question, Does our globe consist of but one kind of matter, or of several; and if of several kinds, of how many? He commences his practical work by arranging in classes all known substances according to their differences in external or sensible properties, such as weight, colour, odour, taste, &c.

10. The preliminary labour is to a great extent done to the hands of the chemist by his brethren the students of the other sciences, so that he receives, as it were, from the geologist and mineralogist, rocks and minerals, such as sandstone, granite, marble, opal, garnet, chalcedony; from the botanist and anatomist, woody fibre, sap, colouring matter, milk, blood, bone; and from the natural philosopher, oil, water, alcohol, and other liquids, besides solids and gases, with their sensible or physical characters accurately noted and recorded for his use.

11. The first point the chemist seeks to ascertain in reference to every substance, whether derived from the animal, vegetable, or mineral kingdom, is, Does it consist of one kind, or of several kinds of matter? The determination of this point enables him to make a primary division of all bodies into two great classes—simple and compound. Simple bodies consist of but one ingredient, as, for example, the various metals; compound bodies of more than one constituent. Thus water contains two, sugar three, dry alum four, and pure white of egg six.

12. The processes which the chemist employs in order to discover whether bodies are simple or compound are various. The most common, perhaps, of all the agents which he brings to bear upon them is heat. Nearly every substance, for example, derived from plants and animals can be proved to be compound by simply heating it. Other bodies which resist the decomposing power of high temperatures, give way at once when exposed to the action of electricity, and separate into their constituent parts. Many compounds which are indifferent both to heat and electricity are at once broken up by simply mixing them with other substances. Thus the strong acids, nitric, sulphuric, and hydrochloric, decompose with great rapidity the majority of mineral substances. Light, especially sunlight, has a considerable power of effecting decomposition, and so have purely mechanical agencies, such as pressure and violent concussion. The forces resident in living plants and animals, which, in our present ignorance of their exact nature, we distinguish as if quite peculiar by calling them *vital*, because they are under the influence of vitality, have also very remarkable decomposing powers.

13. Those forces may be regarded as the chief agents which the chemist employs for effecting decomposition, and they supply him with the means of distinguishing simple from compound bodies. Compound bodies may, accordingly, be defined to be those substances which, when subjected to heat, electricity, light, mechanical agencies, or the vital forces, applied singly, or taken, where that is possible, together, suffer

resolution or decomposition into two or more ingredients, which cannot, by subjection to the same processes, be similarly decomposed. Simple bodies, on the other hand, are those substances which resist the decomposing power of the forces referred to, and after the most protracted and repeated exposure to their influence, remain with every essential property altogether unchanged.

14. This exposure of substances to all known decomposing forces is spoken of by the chemist as their subjection to chemical *analysis*, a word derived from the Greek *ανα*, *up*, or *back to its sources*, and λυω, *to loose*, and signifying the separation or resolution of any complex or compound thing into its primary constituents, or ultimate elements, or the process by which that resolution is effected. Compound bodies admit of analysis—that is, every substance consisting of two or more ingredients, admits of being analysed or decomposed into those ingredients, so that they can be shewn apart. Simple bodies, on the other hand, consisting of but a single substance, are, in relation to chemical analysis, one and indivisible, and do not therefore admit of being analysed.

15. As analysis is the foundation of all chemistry, though by no means sufficient of itself to constitute it a science, it is of the utmost importance that at the very outset the mode in which it is applied to furnish a basis for the science should be appreciated. To illustrate this, the following examples are given:

16. The most familiar of all liquids—water—was, from a very early period, considered an element or simple body. If a powerful electrical current, however, be sent through it, the force analyses the water into two gases unlike each other, and unlike the water. The last, for example, at ordinary temperatures, is a liquid not itself combustible, and in which ordinary inflammables do not burn. The one of the gases into which it is resolved is called by the chemist hydrogen, and besides many other remarkable properties, is highly combustible. The other gas, named oxygen, causes a lighted body plunged into it to burn with much more brilliancy than in common air.

17. Water, then, is a compound of two ingredients, hydrogen and oxygen. The question now arises, Are the oxygen and hydrogen compounds of two or more constituents, as water is? According to the present experience of chemists, they are not. Heat, light, electricity, and the other agencies already referred to, effect no analysis of them into simpler substances. Both are regarded, accordingly, as consisting entirely of a single peculiar kind of matter.

18. A piece of marble, which is pure limestone, presents no characters, as of colour, weight, density, and the like, by the mere inspection of which we can tell whether it consists of one or of several ingredients. We know, accordingly, that for ages it was looked upon as a simple substance, and called, with a multitude of others, an Earth. If a piece of marble, however, be strongly heated, as limestone is every day in our lime-kilns, it is decomposed or analysed into two totally-unlike substances. The one of these is the familiar body, quicklime, or lime-shell; the other is a gas, which, when it was first observed as derived in this way from marble, was called fixed air, because it had previously been in a state of fixation in the solid limestone.

19. Marble, then, is a compound of at least two substances, lime and fixed air; but are these simple, or may they not be made up of ingredients, as the marble was made up of them? When lime is subjected to a galvanic current, it is decomposed into two bodies, the one a brilliant, yellow-white metal, called calcium, the other the gas oxygen; but neither the calcium, nor, as we have already seen, the oxygen, can by any process be resolved into two or more ingredients. Each appears, like the elements of water, to consist of but one kind of matter. The fixed air, or carbonic acid, in like manner, when heated with certain metals, is resolved into carbon or charcoal, and into the same gas, oxygen, which was found in lime and in water; but the charcoal resists all decomposing agents, and seems, like the oxygen and calcium, to be a simple substance.

20. In the way thus illustrated, the chemist proceeds,

subjecting all substances to his analytical processes; and whenever he comes to one which does not admit of analysis, he sets it apart, and calls it a *simple* or *elementary body.* In the present state of our knowledge, we count sixty-five bodies as simple, elementary, or not susceptible of analysis. The metals are all simple bodies. Thirteen substances which are not metallic belong also to this class.

21. Out of sixty-five elements, then, the thousands of chemical compounds known to us are made up. There is no body which contains them all, or even a majority of them. The greater number of substances contain a very few, and consist of only two, three, four, five, or six ingredients. Some of the simple bodies, moreover, form a much greater number of compounds than others. Certain of them, indeed, occur only in very small quantity in the globe, as constituents of rare minerals.

22. The sixty-five bodies referred to, which cannot be analysed, will hereafter be spoken of throughout this work as the Chemical Elements, or elementary bodies. They bear the same relation to the various compound substances which belong to the animal, vegetable, and mineral kingdoms, that the letters of the alphabet do to the works written in the language which they make up. Thus every English word is a compound of two or more letters, into which it can be grammatically analysed. The twenty-six letters themselves, however, admit of no analysis, but are the primary symbols out of which the language is constructed. Certain of these letters occur much more frequently in words than others; thus one or more vowels are found in nearly every part of speech, whilst the letter Z enters into the composition of very few terms.

23. The chemical elements may thus be called the alphabet of chemistry as a science, and the different compound bodies correspond to the words which are made up of the alphabetical letters. Thus water is like a word of two letters, marble like one of three, alum of four, white of egg of six. We subjoin a list of the chemical elements, to which we shall return again:

TABLE OF ELEMENTARY SUBSTANCES.

Aluminum
Antimony (Stibium)
Arsenic
Barium
Beryllium or Glucinum
Bismuth
Boron
Bromine
Cadmium
Cæsium
Calcium
Carbon
Cerium
Chlorine
Chromium
Cobalt
Copper (Cuprum)
Didymium
Erbium
Fluorine
Gold (Aurum)
Hydrogen
Indium
Iodine
Iridium
Iron (Ferrum)
Lanthanum
Lead (Plumbum)
Lithium
Magnesium
Manganese
Mercury (Hydrargyrum)
Molybdenum
Nickel
Niobium or Columbium
Nitrogen or Azote
Norium
Osmium
Oxygen
Palladium
Phosphorus
Platinum
Potassium (Kalium)
Rhodium
Rubidium
Ruthenium
Selenium
Silicon or Silicium
Silver (Argentum)
Sodium (Natrium)
Strontium
Sulphur
Tantalum
Tellurium
Terbium
Thallium
Thorium
Tin (Stannum)
Titanium
Tungsten (Wolfram)
Uranium
Vanadium
Yttrium
Zinc
Zirconium

24. Analysis, or the resolution of bodies into their simplest ingredients, however, constitutes but half of the characteristic work of the chemist. In the case of a language, we do not merely resolve words into their component letters, but we combine these letters, so as to form new words, such as were not in existence previously. Thus, by analysing the hieroglyphics on the Egyptian monuments into their simplest constituents, we have discovered the grammatical elements of what for centuries was a lost language. We employ the knowledge so attained in reading the Egyptian inscriptions; but we might, in addition, construct new words out of the hieroglyphics, such as no Egyptian ever saw or made use of.

25. In like manner, the chemist does not content himself with merely analysing the compounds which nature presents ready formed to his hand, but determines, by his interference,

the production of new ones, such as did not exist in the world till he effected their formation. Chloroform, for example, affords a striking illustration of a chemical substance which, so far as we know, occurs nowhere ready formed on the globe, but which has been called into existence by human interference within the last few years. It is not to be forgotten, however, that man has no real power of creating chemical compounds. He may bring together two elements which never met till he mingled them; but the combination which occurs between them is not effected by him, but results from the action of certain properties which the Author of all things has conferred upon these elements.

26. It is only, therefore, in a secondary and subordinate sense that the chemist creates. The importance, however, of his office in this respect is not on that account to be overlooked. Few of our more valuable medicines, dyes, pigments, and other substances largely employed in the useful arts, are found native. The greater number of them must be prepared by complicated processes from what may be called the raw material, which alone is furnished by nature. Glass, for example, and soap, are in one sense artificial compounds, for they occur nowhere native; but in another are quite natural combinations, for had there not existed laws of nature determining their production, man could never have caused their formation.

27. This creation of new compounds by the union of their elements is called their production by chemical *synthesis*, a term which stands exactly contrasted in meaning with *analysis*, signifying the binding together or union of bodies previously uncombined. Thus, if we send an electrical current through water, we effect its analysis into oxygen and hydrogen; but if we send an electric spark through a mixture of these gases, their synthesis is determined: in other words, they unite and reproduce water.

28. The chemist's labours, which are thus partly analytic, partly synthetic, may be considered as beginning with Analysis. He prosecutes it till he has resolved the globe, and everything

on it, into sixty-five primary constituents or elements. He then betakes himself to Synthesis—turning round, as it were, and retracing his steps, so as to pass now from simplicity to complexity; and by mingling the sixty-five elements in various ways, creates an endless number of novel substances. These in their turn he subjects to analysis, in order that he may discover their exact nature and composition; and thus Analysis and Synthesis constantly alternate, and frequently proceed together.

29. The prosecution of analysis and synthesis is in great part, however, only a mean to an end. The new elements which the one, and the new compounds which the other brings to light, are each of them carefully studied as to all its properties. Thus the chemist examines, in regard to every substance, simple or compound, its shape, if it be a solid; its specific gravity, whether it be solid, liquid, or gas; its colour, odour, taste; its melting, freezing, or boiling point; its power to refract, reflect, and otherwise modify light; its solubility in water and other liquids; its action on living bodies; the mode in which it affects other chemical substances; the conditions essential to its entering into combination with these, and to its separation from them; the proportion, by weight and volume, in which it combines with unlike bodies; besides many other particulars.

30. It is further to be observed that analysis and synthesis are not the only means by which the chemist extends his science. There are many other important methods of investigation, springing out of the relations of bodies to heat, light, electricity, magnetism, the forces which effect crystallisation, &c., which are constantly had recourse to for the extension of chemistry; but it would be premature to enter at present on the discussion of these.

31. It will quite suffice for the beginner to regard Chemistry as the science which takes cognizance of the fact, that our globe, including its contents and inhabitants, does not consist of one, but of many species or kinds of matter; and which investigates the differences that are presented by those kinds of matter, and

the properties of the bodies formed by their union with each other. To return to our original illustration: if our globe consisted of but one chemical element—for example, were it a ball of lead—the astronomer could still discuss the problems of his science in relation to it; the geologist, and perhaps the mineralogist, would have something to describe concerning it; the natural philosopher would have still more to explain regarding it; but the chemist would have nothing to proclaim in reference to such a globe. For all the sensible characters of a mass of lead, considered alone, fall under the notice of the philosophers previously referred to, who would leave nothing undescribed for the chemist to record.

32. The characteristic office of the chemist is to investigate the *differences* which subsist between unlike kinds of matter; but if there were but one kind—namely, lead—in existence, there could be nothing different to admit of comparison with it; so that in a globe of but one element, there could be no work for the chemist to do. Two elements as constituents of a world—lead, for example, and sulphur—would permit our science to come into action; and its range would widen as the number of elements increased. Our existent Chemistry is the exposition of the differences which subsist between sixty-five elements, and the record of all the properties and material relations of each of these elements, and of all its compounds.

⁂ The word *Chemistry* is derived from the Greek χημεια (chemeia), which occurs for the first time in certain works of the eleventh century, and is used by their writers to signify the *art of making gold artificially*, so that it originally denoted what we now generally indicate by the word Alchymy—namely, the supposed art of transmuting the common metals into gold. The root of the word is exceedingly doubtful. Some derive it from *Ham*, the son of Noah, one of whose immediate descendants is said to have been the first chemist; others from *Chemia*, one of the ancient names of Egypt, in which chemistry is said to have originated; some deduce it from the Coptic root *chems*, obscure or secret; and others from the Greek *chymos*, a liquid or juice—the aqua-regia of the alchemists being the liquid *par excellence*. Several other derivations have been proposed; but all are very uncertain, and none of them throw any light on the modern meaning of the word.

GENERAL PROPERTIES OF MATTER.

33. The general properties of matter are discussed in a separate volume of this series of works, under *Laws of Matter and Motion*, and therefore are not enlarged upon here. There are certain of them, however, which must be briefly referred to, on account of the frequency with which allusion is made to them in all chemical discussions.

34. The masses of matter (liquid, solid, and gaseous) which present themselves at the earth's surface are looked upon as made up of certain minute particles, molecules, or atoms, which, being arranged together in close approximation, build up larger solids, as a massive edifice is constructed by placing a multitude of hewn stones or moulded bricks together. To make the comparison complete, we must suppose the component stones to be very small, and that the joints or spaces between them are invisible. A block of iron is thus represented as the aggregation of a multitude of minute particles of the metal, kept united to each other by the attraction of cohesion, as the attraction of magnetism enables a loadstone to hold in contact with it a piece of steel.

35. In a similar manner a liquid or a gas, in which the particles move freely on each other, may be compared to a battalion of soldiers clad in uniform. If looked at from a considerable distance, such a body of men, when each is motionless, appears as one indivisible mass. If approached more nearly, it is seen to consist of a multitude of individuals

standing close to each other. When the battalion begins to move, it becomes apparent that its alterations in shape, and its movements as a whole, are occasioned by each soldier of which it consists systematically changing his place. Liquids and gases are, as it were, battalions of small particles, each of which corresponds to the individual soldier; but these particles are so minute, that we cannot get sight of them, or perceive the manner in which they determine the movements of the fluids they make up.

36. It is certain that all visible masses consist of particles much smaller than the mass they make up by their union. A cannon ball, for example, can be reduced to portions so minute, that a single one is invisible, and so light, that it will not affect the most delicate balance. Whether, when these particles are reduced to a certain smallness, they do not admit of further reduction in size and weight, or, on the other hand, permit division of their substance to an indefinite extent, has been much discussed by philosophers. The question does not admit of decision by experiment, and speculative philosophy holds the balance even between the rival views.

37. As it will greatly conduce to perspicuity, however, and does not bind the pupil to a final conclusion to adopt for the time one of the two views entertained as to the divisibility of matter, we shall throughout the following pages speak as if there certainly is a limit to the division of particles. Each of these will be regarded as an exceedingly small portion of matter, which, however treated, never becomes smaller, but retains, in all circumstances, the same size, and weight, and shape. The last is best conceived of as round or spherical, so that each particle may be regarded as a microscopically-small sphere, or minute solid ball, some million times smaller than a grain of mustard-seed.

38. These smallest portions of matter are distinguished by three names already introduced, and all of which we shall have occasion to employ. 1. They are called *particles*, or *ultimate particles*, a term which needs no explanation. 2. *Atoms*,

from the Greek *ατομος*, indivisible, a word made use of to imply that the particles of matter are not divisible by any of the forces which cause them to unite with each other, or separate them when combined. An *atom* of a substance is the smallest proportion which will combine with other particles of matter, but which cannot exist in a separate form. 3. *Molecules* are the smallest portions of matter which can exist in a separate state. Thus, an *atom* of water is the least quantity which will combine with other substances; whilst the *molecule* of water is the smallest proportion which will exist by itself, and which might be obtained by the ultimate division of a portion of water.

39. The molecules of matter are constantly exposed to the influence of two opposing forces, which change the physical or mechanical condition of the masses which result from the aggregation of many particles. These counteracting forces are cohesion and heat; the former approximates the particles of bodies, and renders them more dense and solid, or diminishes their volume; the latter (speaking generally) separates the molecules from each other, lessens the density and solidity of the mass, and expands its bulk.

40. These opposing forces, according to their relative intensity, determine three unlike, but most important forms or conditions of matter—those, namely, of solidity, liquidity, and the gaseous state, or gasëity. In one, the attraction of cohesion prevails over the repulsive power of heat. This is the state of solidity. In another, heat has quite overcome cohesion, and we have, as a consequence, the gaseous form of matter. In the third, the opposing forces are balanced, or nearly so, cohesion still prevailing to a certain extent, and the resulting condition is that of liquidity.

41. A solid is distinguished from a liquid and a gas by the fact, that we cannot move one particle of it without moving the whole. In other words, the particles of a solid are bound so firmly and so closely together, that they cannot be made to glide over each other. A propelling force, accordingly, if directed against a single particle or limited portion of a solid,

ither produces no result, or, if effective, moves the entire mass. In liquids and gases, on the other hand, we can put in motion some of the particles, and leave the remainder at rest, or have one set of molecules moving in one direction, and another in an opposite, as we see daily illustrated by the currents passing in unlike directions, which influence bodies of gas and of liquid, such as the atmosphere and the ocean.

42. It thus appears that in solids cohesion is so predominant, that the particles have for the time lost all freedom of motion among themselves. If the solid, however, be exposed to heat, and is not liable to decomposition, its particles immediately begin to move away from each other, and expansion or enlargement of bulk occurs. When the heat is withdrawn, the cohesive attraction recovers its power, and the particles move together again. Thus a rod of iron lengthens when placed in a fire, and shortens again when withdrawn from it.

43. In liquids, as already observed, cohesion manifests itself, though much less strikingly than in solids. Detached drops of water or quicksilver run together into larger globules, shewing that attraction is operating upon them; but the force of cohesion is so small, that the particles are free to move with little obstruction upon each other, so as to admit not only of a general movement of the liquid, but of partial, smaller motions among its molecules. In consequence of the smaller force of cohesion to be overcome in the case of liquids, heat expands them much more than it does solids. Liquid thermometers, accordingly, are more sensitive to the influence of heat than those constructed of metallic rods or bars.

44. Upon the particles of a gas, cohesion has ceased to exert any power; they repel, instead of attracting each other, and when relieved from pressure, or raised in temperature, recede from each other to the utmost attainable limit. Gases, as well as liquids and solids, contract or diminish in volume when cooled, but not for the same reason as these do—namely, because the withdrawal of heat has allowed cohesion to come into play—but simply because the diminution of the

temperature of a gas lessens the mutual repulsive action of its molecules, so that they do not recede so far from each other.

45. All chemical substances, then, whether simple or compound, present themselves as solids or fluids, the term fluid being used as a generic or general one to include two species or kinds, *liquid fluids*, or *liquids*, and *elastic fluids*, or *gases*. The same substance often presents itself in all the three forms, according to the temperature at which we examine it; and its chemical properties differ materially according as it is a solid, a liquid, or a gas. No other example need be given at present than that of water, which at the freezing-point is a crystalline solid; at ordinary temperatures, a limpid liquid; and at its boiling-point, an invisible vapour. Ice, liquid water, and steam, differ strikingly in physical and chemical relations from each other.

WEIGHT—SPECIFIC GRAVITY—ATOMIC WEIGHT.

46. Weight, or the pressure downwards (or rather towards the centre of the earth) which all bodies exhibit, in obedience to GRAVITY, is a character of matter which each of the physical sciences requires to consider. Chemistry is specially concerned with three relations of weight, which should be clearly apprehended by the student, and carefully distinguished from each other. These are—1st, *Absolute Weight;* 2d, *Specific Weight;* 3d, *Atomic Weight.* Absolute weight is a term used as the expression of the whole amount of ponderable matter in any body. Thus the absolute weight of one fluid ounce of pure water (half a wine-glassful) is 437½ grains.

47. In order to express absolute weight, we have recourse to one or other of the divisions or systems of weights in common use, as in the preceding example we have employed one of the denominations of the Avoirdupois or Imperial system. This is the one most frequently used by chemists in this country—as, for example, in stating the results of the analysis of mineral waters, &c.—and will be generally adopted in the following pages. The value of the grain, however, is the same in all systems; so that, by generally giving weights in grains, we shall avoid any confusion between the two. The Avoirdupois or Imperial pound consists of 7000 grains.

48. Those who perform experiments will often find it essential to success to weigh accurately the materials which are to be

employed. It should be kept in remembrance, accordingly, that the small weights which accompany the scales used by the apothecary are, when taken in grains, identical in value with Imperial weight. The phrase 'Apothecaries' Weight' refers only to the names given to the multiples of the grain, not to a difference in the grain itself. Thus the apothecary has a weight which he calls a scruple, and another which he calls a drachm—denominations neither of which occurs in Imperial weight; but the scruple is nothing more than twenty, and the drachm sixty, Imperial grains. The weights, therefore, of the apothecary's box may be employed, whether we are following the avoirdupois or apothecaries' system of division.

49. *Specific Weight*, or, as it is generally called in this country, *specific gravity*, is a phrase employed to express the relation that subsists between the absolute weight of any substance and the volume or space which that weight occupies. In order to ascertain it, the same bulks or volumes of substances are taken, and the weight of these identical volumes determined. Bodies which, within the same volume, contain the same amount of ponderable matter, are said to have the same specific gravity. If one of them weigh more than another, it has a higher specific weight than it; if it weigh less, its specific gravity is smaller. Thus, if two pieces of iron be taken, each of exactly the same dimensions as the other, and be placed, the one in one pan of a pair of scales, and the other in the opposite, they will exactly balance each other, as their weights will be identical. Here, within the same space, or bulk, or volume, we have exactly the same amount of ponderable matter.

50. If, however, we substitute for one of the pieces of iron a piece of the metal platinum, of precisely the same dimensions, and place the metals in opposite scales, we shall find that they do not balance each other, as the two pieces of iron did, but the platinum will prove much the heavier; so that if, for example, the piece of iron we took weighed 7·8 grains, the mass of platinum of the same size would weigh 21·5, or the latter would be about three times heavier than the former. Within the

same space, then, there are three times as much ponderable matter in platinum as there is in iron, which is expressed by the chemist by saying that the specific gravity of platinum is three times greater or higher than that of iron.

51. Specific gravity is thus the expression of the difference that subsists between the weights of equal volumes of bodies; or it may be more shortly stated thus: the specific gravities of bodies are the relative weights of equal volumes of them. In order to express the difference between the weights of equal volumes, we fix upon one body, and call its density 1, or unity, writing after it the figure 1, or 1000. Bodies which have a greater specific gravity have that indicated by some higher number than 1; bodies which have a lower specific gravity by a number less than unity, according to their relative differences in weight.

52. For many reasons, water has been selected as the body whose density shall be called unity, in so far as liquids and solids are concerned. Water, accordingly, is said to be the standard of specific gravity for liquid and solid bodies. Thus, if we compare the weight of a certain volume of water with exactly the same bulk of iron, we shall find that the iron is nearly 8 times heavier than its own volume of water, whilst platinum is 21½ times denser than an equal bulk of that liquid. We express this numerically thus:

Water, sp. gr. (specific gravity).............	1	or	1000
Iron, sp. gr..	7·8	or	7844
Platinum, sp. gr..................................	21·5	or	21,500

In other words, these numbers express this fact, that a space which, when quite filled at a certain temperature and pressure of the atmosphere, contained 1000 grains of water, would, at the same temperature and pressure, hold 7844 of iron and 21,500 of platinum.

53. Gases are so much lighter than water—air, for example, being 815 times lighter—that it would be found extremely inconvenient to make water the standard of specific gravity for elastic

fluids. Air, accordingly, is substituted for it, and the specific gravity of air is called 1·000 or 1000. Thus the gases carbonic acid and chlorine are heavier than air; nitrogen, on the other hand, is lighter. The exact numbers denoting their specific gravity are the following:

Air	1·000	or 1000
Nitrogen	0·9713	or 971·3
Carbonic Acid	1·529	or 1529
Chlorine	2·470	or 2470

54. These numbers, like those already given, express the fact, that a vessel which, when full of air at a certain temperature and pressure, contains a thousand grains (1000) of that gas, will, at the same temperature and pressure, though filled quite as full, contain only 971·3 grains of nitrogen; whilst, when filled no fuller by the heavier gases, it will contain 1529 grains of carbonic acid and 2470 of chlorine. The containing vessel having been the same in all the trials, and filled each time, there cannot be any difference in the volumes of the gases taken. The difference in weight is determined solely by the fact, that within exactly equal spaces, different bodies contain unlike quantities of ponderable matter.

55. Many precautions and niceties are necessary in the practical determination of specific gravity. The methods and minutiæ, which require attention, must be learned from works on natural philosophy. No character of a body, however, is more frequently referred to by the chemist than its specific gravity; hence our detailed discussion of it. The specific gravity of every important substance will be mentioned whilst describing its properties.

56. *Atomic Weight*, or, as it might be called, *combining proportion*, is the term used to express the relation that subsists between the different proportions by weight in which substances unite chemically with each other. Thus common salt, which is the chloride of sodium, consists of two bodies, chlorine and sodium, and contains these ingredients, not in a variable, but in a quite

fixed or constant proportion by weight, and each element in a different proportion. Every specimen of common salt contains 23 parts of sodium and 35½ parts of chlorine. This fact the chemist expresses by saying that the atomic weight of sodium is 23, and the atomic weight of chlorine is 35·5. He calls it *atomic* weight, because he assumes that the difference in question depends upon the fact, that every ultimate particle or atom of sodium or of chlorine possesses these weights respectively. This relation of weight, however, cannot be understood till certain important laws have been explained. We adjourn its discussion, therefore, till they have been considered.

CHEMICAL AFFINITY.

57. As there is of necessity a much greater number of compound than of simple chemical substances, one of the earliest things which the chemist has to consider is the nature of those compounds, and the means by which they are to be distinguished from their elements, from each other, and from mechanical mixtures. We offer here, accordingly, some preliminary observations on those points.

58. Every chemical compound consists of at least two elements, although, as we have seen already, it may contain many more. For simplicity's sake, however, we shall confine ourselves in the following remarks to a compound of only two elements, and select, in the first place, water as the example. When the gases oxygen and hydrogen are mingled together, they become uniformly diffused through each other, but no chemical combination occurs between them. If, however, a light be applied to the mouth of a vessel filled with the gases mixed in certain proportions, or an electric spark be sent through the mixture, great evolution of heat and light occurs, a sharp report or explosion is heard, and the gases become changed into steam, which, as it cools, condenses into liquid water. The oxygen and hydrogen are now said to have entered into chemical combination, and to have formed water.

59. The smallest conceivable quantity, or minutest particle, of water is supposed to consist of two atoms of hydrogen and one atom of oxygen, not fused or run into one larger particle, as several drops of a liquid metal like quicksilver flow into a

bigger drop, but consisting of distinct and unlike particles, kept near each other by a peculiar constraining force, to which the name has been given of *chemical affinity.* So long as the particles of oxygen and hydrogen are under the influence of this power, they cease to present the properties which characterise oxygen and hydrogen when uncombined—the associated particles acting for the time as if they were but one, which manifests the properties peculiar to water. When water, again, is decomposed—for example, by a galvanic current—the particles of hydrogen separate from those of oxygen, and all those of one kind go together; the properties of water cease to appear, and those of hydrogen on the one hand, and of oxygen on the other, become manifest.

60. Chemical affinity was at one time called chemical attraction, as if it were a force, like mechanical attraction or cohesion, bringing the molecules of bodies into closer contact. There can be no doubt that in many cases the particles of elementary bodies do come nearer each other when they combine chemically; thus, if two measures of hydrogen and one of oxygen be caused to unite, three measures of steam, or water vapour, are not procured, but only two; or the particles of oxygen and hydrogen have approached so much closer to each other, that they occupy only two-thirds of the space they did before they combined. In other cases, however, compounds are found to occupy exactly the same space as their elements did before combination, as in the combination of one volume of chlorine with one volume of hydrogen, which go to form two volumes of hydrochloric acid gas. Where this happens, there is no evidence that an attracting or approximating force is at work upon them.

61. The student is recommended, therefore, not to employ the term chemical attraction, but rather to use the more metaphorical one *affinity*, which expresses only, that in every chemical compound there is an unknown force at work, which acts as a bond or tie, or link of union, between its elements. In virtue of this, they do not separate so long as it is in operation; but remaining together, confer upon the compound the properties which distinguish it from its elements, and from a mere

mechanical mixture of these. It is necessary, nevertheless, to point out the characters which distinguish a mechanical combination, resulting from the operation on the particles of matter of the attraction of cohesion, from a chemical compound, which is produced by the influence of affinity.

62. In the first place, then, chemical affinity acts only upon unlike particles. It does not, for example, unite molecule of iron to molecule of iron, or of sulphur to sulphur, or of oxygen to oxygen, or of hydrogen to hydrogen; but comes into play only when the atoms consist of different kinds of matter. It binds sulphur, for example, to iron, and oxygen, as we have seen, to hydrogen. Cohesion, on the other hand, is seen most strikingly manifested when uniting particles of the same kind of matter to each other; thus it unites iron to iron, water to water, and marble to marble. But adhesion, like chemical affinity, also unites dissimilar particles: one metal, for example, can be made to adhere to another by powerful compression, as when silver is inlaid with steel. Copper, by a different process, is mechanically united to tin; and iron is coated with zinc. Equally striking, and more familiar examples, are furnished by the action of gum, paste, or glue, when employed to unite unlike substances, as paper and leather, or wood and stone.

63. A mechanical combination, however, of unlike kinds of matter, is readily distinguished from a chemical compound by the following characters: The properties of the mechanical combination are always either the sum, or the mean or average of the properties of its components. Thus a watch is a mechanical aggregation of gold, silver, copper, steel, enamel, jewels, and glass. Its absolute weight is the sum of the absolute weights of all those; its specific gravity is the mean of their several densities; nor has it any properties which are not either equal to, or the sum of, the properties of its constituents, or the mean or average of these. So also the physical characters of the board of a book are exactly the sum or the mean of the properties of the leather, paper, pasteboard, and glue, which make it up.

64. The properties of a chemical compound, on the other hand, are not, with one exception, so far as we at present know, either the sum or the mean of those of their components. The exception occurs in relation to absolute weight, which, as well in chemical as in mechanical compounds, is exactly the sum of the weights of the constituent ingredients. The other properties are all new, so that a knowledge of the qualities of the elements does not enable us to anticipate or predict what the properties of the compound will be, which we can to a great extent foresee in the case of mechanical combinations. Thus the specific gravity of steam is not identical with that of either oxygen or hydrogen, or that of a mixture of them; nor is it the sum or the mean of the densities of those gases, taken singly or mingled. Its action on light, its conducting power for sound, its relation to combustion and to animal life, and a multitude of its other physical characters, are totally unlike those of a mechanical mixture of oxygen and hydrogen.

65. Of the changes in physical properties which chemical affinity produces, none is so likely to strike the beginner as the difference in colour between a chemical compound and its elements, or a mixture of these. Thus, if the pale yellow sulphur and the bluish-white quicksilver be heated together, they form the bright red vermilion, a tint which cannot be produced by any mechanical mixture of blue, yellow, and white colours. In like manner, if a piece of the reddish-brown copper be dissolved in the colourless liquid nitric acid, it forms a deep blue compound. When the bluish-black body iodine combines with the metal lead, the two give rise to a bright yellow substance. When charcoal and sulphur unite, the resulting compound is neither black nor yellow, nor of any intermediate tint, but is as colourless as water. Multitudes of other examples might be given, but these may suffice so far as change of colour is concerned.

66. The other properties of the chemical elements, however, are quite as much altered when they combine as their tints are. Thus the heavy metal antimony, which we are accustomed to

see as a massive solid, forms an invisible gas when it combines with hydrogen. The greenish-yellow gas chlorine, on the other hand, when it unites with quicksilver, forms white crystals of corrosive sublimate. Solid sulphur and charcoal change into a very volatile liquid. Phosphorus, which resembles wax in appearance, and oxygen, a colourless invisible gas, form phosphoric acid, a body exceedingly like snow. Nitrogen and oxygen have no taste; neither has a mixture of them. One of their compounds, laughing-gas, is pleasantly sweet to the palate; another, nitric acid, intensely sour. Charcoal, hydrogen, and oxygen are all tasteless; gum is one combination of them, arrow-root another, sugar a third.

67. Chlorine gas has a suffocating odour; common salt, of which it forms more than one half by weight, is odourless. Charcoal and hydrogen, on the other hand, have no odour; nevertheless, a large number of our choicest perfumes, such as oil of bergamot, oil of thyme, and oil of orange-peel, consist solely of those two elements. In like manner the scentless nitrogen and hydrogen are the only constituents of one of the most odorous of all substances, gaseous hartshorn, or ammonia.

68. Again, the deadly poison prussic acid is made up of carbon, hydrogen, and nitrogen, which, taken singly or mixed, are not injurious to animal life. Oxalic acid, another poison, consists of charcoal, hydrogen, and oxygen. The same elements constitute spirits of wine and sulphuric ether.

69. The preceding examples of change in specific gravity, colour, form, taste, odour, and relation to living animals, will serve, in the meanwhile, to prove how totally dissimilar in properties a chemical compound is from a mere mechanical mixture of its elements. Every chemical compound exhibits this character of newness of properties. No substance, indeed, is entitled to be called a chemical compound in which the properties are only the sum or the mean of those of its ingredients.

70. The characteristic difference between the products of mechanical attraction and chemical affinity may be illustrated

thus, the least complex kind of combination being selected to be commented on: If we call the one element of the mechanical mixture A, and the other B, then the mixture itself is equal merely to A plus B, or A added to B, each of which can be traced in the compound. But when A and B represent the elements of a chemical compound, although analysis proves that they are as distinctly present in it as they are in the mechanical mixture, we lose all traces of their separate existence, and their combination is equivalent to a perfectly new substance which, judging by its properties, we should not call AB, but distinguish by a special letter, as by naming it C.

71. Having thus, then, settled what a chemical compound is, we are now to consider how many kinds of such compounds there are. It may be observed, as preliminary to what we have to say on this subject, that compounds differ in complexity. Thus marble consists, in the first place, of two bodies—carbonic acid and lime; but each of these, in its turn, consists of two bodies—the carbonic acid of charcoal and oxygen, lime of the metal calcium and oxygen. Alum consists primarily of four bodies, potass, alumina, sulphuric acid, and water; but all of these are themselves compound, oxygen being present in each of them, united to metals (aluminum and potassium) in alumina and potass, to sulphur in sulphuric acid, and to hydrogen in water.

72. Many compounds, also, although totally different in properties, contain exactly the same elements, but these are in different proportions. Thus the medicinal substances calomel and corrosive sublimate contain the same two ingredients, chlorine and mercury; but calomel contains twice as much mercury as corrosive sublimate. We are now ready to discuss the laws according to which the simpler compounds are formed out of the elements, and the more complex combinations out of the simpler compounds.

LAWS OF COMBINING PROPORTION.

73. The laws of chemical combining proportion are four in number. They refer to combination by *weight*, not to combination by volume, which will be referred to in another portion of the work. They explain certain exceedingly simple principles which regulate the relative quantities or proportions by weight, according to which chemical substances unite with each other to form combinations. A knowledge of them is essential to the successful prosecution of chemistry, whether as a science or an art. It is of the utmost importance, therefore, that the student should clearly comprehend them.

74. Before mentioning those laws, we direct attention to another, which does not refer to the quantity or weight of elements or ingredients in a body, but simply to the *nature* of its constituents. This law may be called THE LAW OF CONSTANCY OF ELEMENTS OR INGREDIENTS. We use the word element here in the sense in which we have formerly defined it, to indicate the simplest chemical substances. The term ingredient, for distinction, we apply to a body, itself a compound, but which, by union with others, forms a combination still more complex than itself. Thus in water we have two elements, oxygen and hydrogen; whilst in marble we have two non-elementary components, or, as we shall call them, ingredients—carbonic acid and lime.

75. The law, then, we are about to announce applies equally to the simple element and the compound ingredient. It may be expressed thus: THE SAME COMPOUND CONSISTS INVARIABLY OF THE SAME ELEMENTS OR INGREDIENTS. Water, for example, is invariably composed of oxygen and hydrogen, and of nothing else; common salt consists equally invariably of chlorine and sodium; and vermilion of sulphur and mercury. *Marble*, in like manner, always exhibits as its constituent ingredients carbonic acid and lime; *Glauber's salt*, always sulphuric acid and soda; *sal ammoniac*, always chlorine and ammonium. To this law there is no exception, so that one accurate analysis of a compound for ever decides the nature of its ingredients.

76. We now proceed to the laws of proportion. The first is best entitled THE LAW OF CONSTANT PROPORTION. It teaches that THE ELEMENTS OR INGREDIENTS WHICH FORM A CHEMICAL COMPOUND ARE ALWAYS UNITED IN IT, IN THE SAME PROPORTION, BY WEIGHT. Water not only consists invariably of oxygen and hydrogen, but the proportions in which these elements are present are 16 parts of oxygen to 2 parts of hydrogen, in other words, the weight of oxygen present is always eight times greater than that of hydrogen. Common salt always contains 35½ parts of chlorine to 23 of sodium; vermilion, 32 of sulphur to 200 of mercury; so also marble has always 44 of carbonic acid to 56 of lime; Glauber's salts, always 80 of sulphuric acid to 62 of soda; sal ammoniac, 35½ of chlorine to 18 of ammonium.

77. In virtue of this law, numbers can be found for all substances, simple or compound, expressing the relative quantity by weight in which they combine with all other bodies. We shall illustrate this more fully after explaining the second law. In the meanwhile, however, it is important to observe how much chemistry is simplified by the existence of such a law as we have just explained. We have mentioned already that a single accurate analysis for ever settles what the ingredients of a compound are. It equally settles what the proportion of these ingredients is.

78. It is true that in actual practice the chemist never contents himself with a single analysis, but he does this, not because he expects one specimen, for example, of water, to differ in composition from another, but because his methods of analysis, however refined, still fall far short of absolute accuracy. It is essential, accordingly, to make several analyses which yield results differing very slightly from each other, and the mean or average of those several determinations is taken as representing the true composition of the body. After all, however, the several imperfect analyses are only equal to a single accurate one.

79. In the case of mechanical mixtures, on the other hand, or of combinations, consisting partly of definite chemical compounds, and partly of indefinite mixtures, the labours of the chemist are enormously greater, and one analysis applies only to the particular specimen upon which it is made. Thus clay, mortar, garden earth or soil, many dyes, perfumes, and medical preparations, &c., are not constant chemical compounds. To determine the composition of a single specimen would require, as in the case of a chemical compound, several analyses, the mean of all of which should afterwards be taken. But the very next parcel of the substances named, which called for a knowledge of its composition, would require an analysis to be made as carefully as if no other specimens of those bodies had been previously examined.

80. It is otherwise with chemical compounds. The composition of one specimen of water is the composition of all specimens of water. The marble of Italy is identical with the marble of Ireland. The vermilion made in China is identical with that sold in England. If the analytical chemist's labour is thus greatly abridged by the existence of the law we are considering, the memory of the student is not less aided by it. If the composition of a chemical compound be once apprehended, it will not afterwards require correction or enlargement, or apply with a certain truth to one specimen, but with a quite different one to another.

81. The service which a knowledge of this law renders to chemistry as a practical art is not less striking. In the preparation of dyes, pigments, medicines, metallic alloys such as brass, and important chemical compounds such as glass, soap, carbonate of sodium (washing soda), and the like, the chemical manufacturer can avoid all useless waste of material on the one hand, and all unwise economy of it on the other. There is one proportion, and one only, in which the ingredients of the substance he is manufacturing require to be supplied. The employment of more than that proportion is a waste of material; the employment of less is a detrimental withholding of it. We shall have more to say of this law after explaining the next.

82. The second law of combining proportion is a little more intricate than the first. It is named THE LAW OF RECIPROCAL PROPORTION, and teaches that IF TWO BODIES COMBINE IN CERTAIN PROPORTIONS WITH A THIRD, THEY COMBINE IN THE VERY SAME PROPORTIONS WITH EACH OTHER. Thus 32 parts of sulphur combine with 16 of oxygen, and 56 parts of iron combine with 16 of oxygen; but 32 parts of sulphur is the very quantity that combines with 56 of iron. We may reverse the numbers: 16 of oxygen combine with 56 of iron, and 32 parts of sulphur with 56 of iron; but 16 of oxygen is the very quantity that combines with 32 of sulphur. Or a third time: 16 oxygen and 56 iron combine respectively with 32 sulphur; but 56 iron is the quantity that combines with 16 oxygen.

83. The law of reciprocal proportion may also be stated in another way, which brings out its importance more clearly; THE PROPORTION IN WHICH ANY TWO BODIES COMBINE WITH EACH OTHER, IS THAT IN WHICH THEY COMBINE WITH EVERY OTHER. Thus the proportion in which chlorine and hydrogen unite with each other is as 35·5 to 1; in other words, a given weight of hydrogen always unites with 35½ times its weight of chlorine, or in that proportion; or, reversely, a given weight of chlorine unites with a weight of hydrogen which is 35½ times smaller, or more or less in that proportion.

84. But when each of these bodies is made to unite with all the other bodies with which it can combine, the same proportion is maintained. The compounds of sulphur contain a weight of sulphur twice greater than the similar compounds of oxygen do of oxygen. Thus sulphur combines with carbon to form a volatile liquid called *bisulphide of carbon;* and oxygen combines with carbon to form a gas called *carbonic acid* (more strictly, *carbonic anhydride.* In both these compounds the amount of carbon may be represented by the same number, 12; but the amount of sulphur in bisulphide of carbon being 64, is twice greater than the amount of oxygen in carbonic acid, being 32; or sulphur and oxygen, when they unite with carbon, exhibit the same proportion, 64 to 32, which is equal to 32 to 16, which they shew when uniting with each other: and what is said here of carbon applies to all the elements. Each of them unites with a proportion of sulphur twice greater than that of oxygen, and each of them has one fixed proportion in which it combines with all the rest.

85. This law may be regarded as an extension of the first, which simply taught that the same compound always contains the same quantity of the same ingredients. The law we are discussing goes further, and shews that the proportion in which an element or ingredient occurs in one compound is likewise the proportion in which it occurs in all compounds. Thus, if we call the proportion of oxygen 16, and that of sulphur 32, we shall find that the same numbers will suffice to express the relative proportions in which hydrogen and oxygen unite respectively with all other bodies.

86. It is in relation to this law more than to the others that the combining weights of bodies are termed their *atomic* or *combining proportions.* The law announces that a certain weight of one body enters into combination with a certain but different weight of another in the construction of a similar compound—24 parts by weight of magnesium, for example, go as far in combining with 16 of oxygen to form an oxide, as 56 of iron, 65 of zinc, or 197 of gold. The same remark

applies to the different but combining proportions of all the other substances referred to.

87. In virtue of the laws of constant and reciprocal proportion, a number can be found for every body, simple or compound, expressing the ratio in which it combines with every other. Any series of numbers may be taken to represent these combining ratios, provided a certain proportion is maintained among them. Thus analysis demonstrates, as we have seen already, that the combining quantity of oxygen is 16 times greater than that of hydrogen; so also it shews that the combining quantity of charcoal or carbon is 12 times greater than that of hydrogen; that of nitrogen 14 times; that of sulphur 32 times; that of iron 56 times.

88. Now any scale of numbers may be taken to represent these relative combining quantities, provided only that the number for carbon be 12 times greater than that for hydrogen; that for oxygen 16 times greater; that for nitrogen 14 times; that for sulphur 32 times; and that for iron 56. Thus we might call iron 1; nitrogen would then be $\frac{1}{4}$ or 0·25, and hydrogen would be $\frac{1}{56}$. Or oxygen might be made 1, in which case hydrogen would have its combining quantity expressed by $\frac{1}{16}$, and sulphur by 2. We may give any value we please to any one of the elementary bodies we choose to fix upon for a commencement, and call it 1, 10, 100, 1000, $\frac{1}{2}$, $\frac{1}{4}$, or any other integer or fraction; but here our liberty ceases. The relations between the numbers are absolute, though their individual value is not; and from the settled figure we must count upwards or downwards, or both ways, so as to maintain inviolate the relative values throughout the series.

89. Different scales of combining numbers, accordingly, are in use among chemists. Thus, for analytical purposes it is preferable to call oxygen 100; but in teaching, it is found much more convenient to begin with hydrogen, and to call it 1, so that we count only upwards. The numbers in this scale are all small, and do not, in the majority of cases, go beyond two integers. We subjoin this scale at full length, but before

introducing it, place side by side, for the sake of comparison, the combining weights of some of the elementary bodies on the hydrogen and oxygen scales:

Name of Element.	Hydrogen Scale. Hydrogen equal to 1.	Oxygen Scale. Oxygen equal to 100.
Hydrogen	1	6·25
Oxygen	16	100
Carbon	12	75
Nitrogen	14	87·5
Sulphur	32	200
Iron	56	350

90. Those numbers follow exactly the same proportion; 6·25 bears the same relation to 75 that 1 does to 12; 87·5, the number for nitrogen, is exactly 14 times greater than 6·25, the number for hydrogen. The same numerical relation, accordingly, is expressed by both scales. We shall always employ the hydrogen series, as giving small numbers easily apprehended and remembered.

91. Tables such as the following are said to represent the *combining proportions* or *atomic weights* of substances. The table we give includes only the elementary bodies; but when we have discussed the remaining laws of combining proportion, we shall find that special tables are not needed for compound substances. The object and meaning of the letters named *symbols* placed opposite each element will be explained in a future paragraph:

TABLE OF ELEMENTARY SUBSTANCES.

Names of Elements.	Symbols.	Atomic Weights.	Names of Elements.	Symbols.	Atomic Weights.
		Hydrogen = 1.			Hydrogen = 1.
Aluminum	Al	27·5	Niobium or Columbium	Nb	97·5
Antimony (*Stibium*)	Sb	122	Nitrogen	N	14
Arsenic	As	75	Norium	No	...
Barium	Ba	137	Osmium	Os	199·2
Beryllium or Glucinum	Be	14	Oxygen	O	16
Bismuth	Bi	210	Palladium	Pd	106·6
Boron	B	11	Phosphorus	P	31
Bromine	Br	80	Platinum	Pt	197
Cadmium	Cd	112	Potassium (*Kalium*)	K	39
Cæsium	Cs	133	Rhodium	R	104·4
Calcium	Ca	40	Rubidium	Rb	85·4
Carbon	C	12	Ruthenium	Ru	104·4
Cerium	Ce	92	Selenium	Se	79·5
Chlorine	Cl	35·5	Silicon or Silicium	Si	28
Chromium	Cr	52·5	Silver (*Argentum*)	Ag	108
Cobalt	Co	59	Sodium (*Natrium*)	Na	23
Copper (*Cuprum*)	Cu	63·5	Strontium	Sr	87·5
Didymium	Di	96	Sulphur	S	32
Erbium	E	...	Tantalum	Ta	137·6
Fluorine	F	19	Tellurium	Te	129
Gold (*Aurum*)	Au	197	Terbium	Tr	...
Hydrogen	H	1	Thallium	Tl	204
Indium	In	71·8	Thorium	Th	119
Iodine	I	127	Tin (*Stannum*)	Sn	118
Iridium	Ir	198	Titanium	Ti	50
Iron (*Ferrum*)	Fe	56	Tungsten (*Wolfram*)	W	184
Lanthanum	Ln	92·8	Uranium	U	120
Lead (*Plumbum*)	Pb	207	Vanadium	V	137·2
Lithium	Li	7	Yttrium	Y	68
Magnesium	Mg	24	Zinc	Zn	65·2
Manganese	Mn	55	Zirconium	Zr	89·6
Mercury (*Hydrargyrum*)	Hg	200			
Molybdenum	Mo	96			
Nickel	Ni	59			

92. The third law of combining proportion is related to the circumstance, that the same elements in almost every case combine

in more than one proportion to constitute several compounds. If this, in truth, were not the fact, we should never succeed, even with sixty-five elements at our disposal, in accounting for the enormous variety of substances found in our globe. This law is named that of MULTIPLE PROPORTION, and enforces the truth that WHEN ONE BODY COMBINES WITH ANOTHER IN SEVERAL PROPORTIONS, THE HIGHER PROPORTIONS ARE MULTIPLES OF THE FIRST OR LOWEST. Thus oxygen and hydrogen are contained in water in the ratio of 16 parts of the former to 2 (being twice 1) of the latter. Those elements, however, unite to form a second compound, named the peroxide of hydrogen, or oxygenated water, in which the oxygen is to the hydrogen in the proportion of 32 to 2 (being 16 to 1), or the hydrogen remaining the same as in water, there is exactly *twice* as much oxygen.

93. The illuminating power of coal-gas is owing to the presence in it of two substances, each a compound of carbon and hydrogen. In the one (olefiant gas) there are 12 parts by weight of carbon to 2 of hydrogen. In the other (fire-damp), 12 of carbon to 4 of hydrogen; or the weight of carbon being the same in both, there is exactly twice as much hydrogen in the second as in the first. A substance named the protoxide of manganese contains 55 parts of the metal manganese to 16 of oxygen. Another compound of the same elements, named black oxide of manganese, contains 55 parts of the metal to 32 of oxygen. A third combination, manganic acid, 55 of the metal to 48 of oxygen: 32 is twice 16, and 48 is thrice 16; so that the amount of oxygen in the black oxide is a multiple of that in the protoxide by 2; and the oxygen in manganic acid a multiple by 3.

94. If we now write down in a table the compounds we have named, the multiple relation will be more clearly perceived:

Water........................ = Hydrogen 2......Oxygen 16.
Peroxide of Hydrogen....... = Hydrogen 2......Oxygen 32, or twice 16.

Olefiant Gas................... = Carbon 12........Hydrogen 2.
Fire-damp....................... = Carbon 12........Hydrogen 4, or twice 2.

Protoxide of Manganese.... = Manganese 55...Oxygen 16.
Black Oxide of Manganese. = Manganese 55...Oxygen 32, or twice 16.
Manganic Acid............... = Manganese 55...Oxygen 48, or thrice 16.

95. One of the most remarkable examples of this law occurs in the compounds of nitrogen and oxygen, which are five in number. The proportion of nitrogen may be represented to be the same in all by the number 14, or a multiple of that by 2 (being 28), while that of the oxygen may be expressed by 16 or a multiple of that figure. The first member of the group contains 16 of oxygen; the second substance has 32 of oxygen, or twice 16; the third member of the group contains 48 of oxygen, or three times 16 the proportion of oxygen in the lowest; whilst the fourth substance contains 64 of oxygen, or four times 16; and the fifth member of the series has 80 of oxygen, or five times 16. The four higher proportions are thus multiples of the lowest by 2, 3, 4, and 5, at which last number, in this case, they stop. This will appear more distinctly by the following table, containing the names of the five compounds of nitrogen and oxygen:

Nitrous Oxide............Nitrogen 28 = 14 × 2...Oxygen 16 N_2O
Nitric Oxide...............Nitrogen 28 = 14 × 2...Oxygen 32 = 16 × 2 N_2O_2
Nitrous Acid...............Nitrogen 28 = 14 × 2...Oxygen 48 = 16 × 3 N_2O_3
Hyponitric Acid..........Nitrogen 28 = 14 × 2...Oxygen 64 = 16 × 4 N_2O_4
Nitric Acid (anhydrous).Nitrogen 28 = 14 × 2...Oxygen 80 = 16 × 5 N_2O_5

96. In every series of compounds we find the same law operating. If a substance can combine with more than 16 parts of oxygen, the least next quantity it combines with is 32. It never combines with $16\frac{2}{3}$, $16\frac{4}{5}$, $16\frac{9}{10}$, or any other fraction whatever; but if it overstep the 16, goes right on to the 32 before it is again saturated. It may go past the 32, but in that case it cannot stop at any intermediate number short of 48. It need not halt at 48, however, if it can go on to 64; or at 64, if it can combine with 80; and it may pass at once from 16 to 80, or to any other quantity, however large, provided it be a multiple of the original 16. The only unalterable decree is, that whatsoever

smallest quantity of one body another can combine with, every higher compound must contain in increasing multiples.

97. The law of multiple proportion furnishes a great help to the memory in recollecting the composition of complex compounds. Analysis only can tell us exactly how much of any ingredient is present in a compound; but of this we are certain before, and indeed without analysis, that each constituent will be present either in its smallest combining quantity, or in a multiple of that. The amount of oxygen in all its compounds may be expressed by 16, or a multiple of 16. All combinations of sulphur contain either 32 parts of it, or if not, then 64, 96, or some other multiple of 32. Iron occurs in quantities of 56, 112, 168, &c.—that is, its quantity, if above 56 parts, can always be expressed by a number divisible by 56 without a remainder.

98. This law modifies in a peculiar way the law of reciprocal proportion. Elementary bodies do not, in all their similar compounds, shew themselves *equivalent* in every respect to each other if taken in their smallest combining quantities. It sometimes happens that two or more combining proportions of one substance are requisite to replace or act in the same manner as one of another body. In every case, however, if we have more than one combining proportion, we have it doubled, tripled, quadrupled, or otherwise presenting itself as a multiple of the lowest combining quantity. This will be particularly referred to in a later part of this treatise. (see pars. 1101—1106).

99. The fourth and last law we have to consider is a very simple one, and will not require much illustration. It may be called the law of COMPOUND PROPORTION, and teaches that THE COMBINING PROPORTION OF A COMPOUND BODY IS THE SUM OF THE COMBINING PROPORTIONS OF ITS COMPONENTS. The combining proportion of water, for example, is found by experiment to be 18 (or a multiple of 18), hydrogen, as before, being taken as unity; but 18 is the sum of 16 parts of oxygen and 2 of hydrogen, its constituents. The atomic weight of carbonic acid appears, upon trial, to be 44; but carbonic acid is found, on analysis, to consist of 12 parts of carbon and 32 of oxygen,

which exactly make up 44. The combining weight of lime is 56, but lime consists of 40 calcium and 16 oxygen, which are also 56. Lastly, marble has the combining proportion 100, but it is composed of 44 carbonic acid and 56 lime, which are also 100.

100. This law, like the last, is modified by the law of multiple proportion. Thus a great number of substances contain water as a constituent. In many of them the quantity is expressible by the number 18. Thus slaked lime contains, for every 56 parts of lime (56 being the combining number for lime), 18 of water. In the greater number of salts, however, which contain water we have more than 18 parts. Thus, an atom of blue vitriol, or sulphate of copper, is associated with 90 parts of water; an atom of Epsom salts, or sulphate of magnesium, with 126; an atom of washing soda, or carbonate of sodium, with 180. Those numbers, however, are all multiples of 18. The first salt contains 5 times 18, the second 7 times, the third 10 times 18 parts by weight of water.

101. The same remark applies to other compounds; but the fact we are explaining does not interfere with the existence of the law of compound proportion, or require its statement to be modified. A multiple of a multiple must be a multiple of the numeral with which the multiplication began. A multiple of 32 must be a multiple of 16; a multiple of 54, one of 18; a multiple of 48, one of 12; and so on. The combining number of a compound body is always the sum of the combining numbers of its components, but these are not necessarily present in their lowest combining quantities—that is, in single combining proportions. Compounds, on the other hand, may contain many atoms or combining proportions of all their ingredients or elements. Crystalline grape sugar, for example, contains 6 atoms of carbon, 12 of hydrogen, and 6 of oxygen.

102. As the combining proportion of a compound body can be found by adding together the numbers expressing the combining numbers of its elements, tables of the combining proportions of non-elementary bodies are not given in treatises on

chemistry as a science. The more important of them, however, are recorded in works discussing chemistry as an analytical art, and will be stated in the following pages.

⁂ The laws of combining proportion, and the atomic theory which occupies the next chapter, cannot be profitably studied by those who are entirely unacquainted with the names and properties of chemical substances. It is advisable, therefore, to postpone the study of the laws and theory till the properties of at least oxygen, hydrogen, and nitrogen, and their compounds, as discussed under these titles, have been explained and illustrated. The student will then be familiar with a sufficient number of examples of combinations in different proportions, to follow, without difficulty, the exposition contained in this chapter; nor is it desirable to adjourn its discussion to any later period than the earliest at which it can be intelligently followed.

ATOMIC THEORY.

103. The laws of combining proportion, which have been explained, are not doubtful theories or hypothetical speculations. They are the expression or statement of facts, ascertained by direct and multiplied observation; and any one who questions their truth, can satisfy himself of their reality by accurately analysing a few chemical compounds.

104. These laws, however, were first made known to chemists by their chief discoverer, Dalton, in connection with a peculiar atomic hypothesis, or, as it is less properly, but more commonly called, theory, which supplied a beautiful and complete explanation of the existence of such laws, and furnished at the same time a very simple and easily-followed mode of teaching them. It was with great ingenuity and boldness conjectured by this chemist that the ultimate atoms of the elementary bodies do not possess the same, but different weights, and that the difference between their weights is identical with that which subsists between the combining proportions of the elements themselves.

105. As oxygen, for example, has a combining proportion sixteen times greater than that of hydrogen, so the ultimate atom of oxygen is assumed to be sixteen times heavier than the ultimate atom of hydrogen. As the combining proportion of nitrogen is fourteen times that of hydrogen, so the atom of nitrogen is supposed to be fourteen times heavier than that of hydrogen: and in like manner the relative weights of the

atoms of the other elementary bodies are supposed to differ by the same numbers that the relative weights of their combining proportions differ by.

106. Dalton, it will be observed, thought that if it were possible by any means to select single atoms of each of the elementary bodies, and weigh them one by one, we should find, *first*, that different atoms of the same element possessed all the same weight, so that whatever was the absolute weight of any one, would be found to be the weight of each of the others of the same kind; and if one atom of hydrogen weighed the millionth of a millionth of a grain, each of the hydrogen atoms would weigh the millionth of a millionth also; *secondly*, we should find that all the oxygen atoms were 16 times heavier than the hydrogen ones; all the nitrogen atoms, 14 times heavier; all the silver atoms, 108 times, and all the gold atoms, 197 times heavier.

107. In short, the proportions in which bodies combine with each other are supposed to depend upon the weights of the atoms which make them up, and to be identical with these weights. All the numbers, accordingly, which, before this hypothesis is considered, represent combining proportions, as soon as it is adopted, come to represent weights of ultimate atoms, or atomic weights. It may seem singular that it should be considered important to explain Dalton's atomic views, seeing that it is not at all certain that there are such things as atoms, much less that they differ in relative weight.

108. The conception, nevertheless, of the combining proportion of each element, as dependent on the special and constant weight of the ultimate particles of which masses of the element consist, greatly facilitates the apprehension and remembrance of the laws of combining proportion. Whether an atom is absolutely indivisible, is not a question which chemistry requires to decide. It is enough for the solution of the problems of the science if we concede that in fact those atoms do not suffer division; in other words, are not lessened in weight when chemical combination or decomposition occurs.

109. It is much less easy to grasp the idea of a constant numerical ratio, or combining proportion, than it is to conceive of a solid ponderable mass, which is as unchangeable in relation to gravity as the weights of a balance. Nor is the value of this latter conception in simplifying the study of chemistry affected by the fact, that the solid, ponderable masses referred to may admit of reduction in size, and therefore in weight, by forces other than chemical.

110. A homely comparison may assist in making this clear. Many of our rare or valuable articles of commerce are offered for sale in fixed quantities, so that the purchaser must either take a certain amount at a time, or obtain none. Thus, attar of roses is brought to this country in small stoppered phials, which the dealer will not open so as to dispose of less than the whole contents of the phial at a time. Still more familiar examples are afforded by the dealers in the more valuable teas, who sell these only in packages of a fixed weight; for example, a pound. Weighed quantities of arrow-root, in like manner, are offered for sale in boxes, which the seller will not open.

111. We may liken the different elementary bodies to substances sold in this way. Each of them may be regarded as furnished by nature, made up into small parcels or quantities having a fixed weight, which is the same for each parcel of the same element. Hydrogen can be obtained in quantities smaller than any of the other elementary bodies. Each little parcel of carbon is 12 times heavier than each little parcel of hydrogen. Nitrogen is supplied in quantities 14 times, and iron in quantities 56 times, greater than hydrogen. None of these bodies is found occurring in nature otherwise than parcelled out in the way we have supposed, and none of them is made up into larger parcels or made down into smaller ones during any chemical change. This is all the atomic theory need be considered as contending for.

112. The beginner, then, adopting this view, may at once exchange for the abstract and shadowy conception of numerical

ratio, or combining proportion, the distinct and easily-apprehended idea of a solid ponderable atom. 1 is to be considered as stamped upon every particle of hydrogen, as if the whole amount of it in the globe had been coined at the same mint into pieces of exactly the same value. Carbon, in like manner, has its atoms stamped with 12 upon them, sulphur with 32, iron with 56.

113. When the elementary bodies, moreover, enter into combination, their atoms bearing the unalterable stamp upon them, follow of necessity laws such as we have discussed in the preceding section. Thus, if every atom of oxygen is 16 times heavier than every atom of hydrogen, then different specimens of water must be identical in composition. Eighteen grains of it will, on analysis, yield 16 grains of oxygen and 2 grains of hydrogen; 18 tons, in exactly the same way, will afford 16 tons of the one element, and 2 of the other, because the constituents of water existing in it in the proportion of 1 atom of the oxygen to 2 atoms of the hydrogen, and the atom being unalterable in weight, every specimen of water must yield 1 atom of oxygen weighing 16 for two atoms of hydrogen each weighing 1, so that it will be found to contain a ninth of its weight of the one gas, hydrogen, and eight-ninths of the other gas, oxygen. The law of *constant* proportion, then, is easily accounted for.

114. The law of *reciprocal* proportion is an equally inevitable result of the constancy in weight of the atom; for if each atom of sulphur is 32 times heavier than each atom of hydrogen, then it will exhibit this excess of weight over the hydrogen atom as much when it combines with one body as with another. Thus, in referring to this law in the preceding section, it was stated that while 32 represents the proportion in which sulphur combines with 16 parts of oxygen, it equally exhibits the proportion in which it unites with 56 of iron, which is equal, upon the atomic view, to saying that if the sulphur atom is 32 times heavier than the hydrogen one when weighed in a state of combination, and therefore along with an atom of oxygen (16 times heavier than the hydrogen atom), then it will continue to

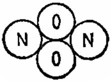
be 32 times heavier than the hydrogen atom, when weighed along with an atom of iron, which is 56 times heavier than that of hydrogen. Neither will its weight suffer any change by weighing it along with any other of the elementary or compound bodies, for the weight of an atom is a constant quantity; it cannot be lessened, or increased, or annihilated.

115. The law of *multiple* proportion is equally necessary, for an atom of one element is the smallest quantity that can be added to a compound containing an atom of it already, and whatever was the weight of the first atom will be that of the second also, so that an exact duplication of the first proportion, without any fractional lack or excess, must take place. And if more than one atom be added at a time, it must be atoms, not an atom and a half, or one and a third, or any other fraction or fragment; for this cannot be, seeing that the atom is chemically indivisible.

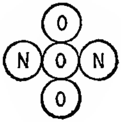
116. In the five compounds of nitrogen and oxygen already considered, the first, which contained 28 parts by weight of nitrogen to 16 of the latter, was to be taken as a compound of two atoms of nitrogen of 14 each with one atom of oxygen, being 16. The second, which was also regarded as containing 28 parts of nitrogen (equal to two atoms of 14 each), was considered to be in combination with 32 of oxygen, because the next highest compound contained two atoms of oxygen, each 16. The third member of the series contained 48 of oxygen, because there are three atoms, each weighing 16; the fourth 64, because the atom is quadrupled; and the fifth, of necessity, 80, for a similar reason. The following diagram will illustrate this. Each atom is represented by a circle with the initial letter, representing the name of the element of which it is an ultimate particle :

1. Nitrous Oxide,

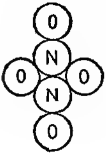
2. Nitric Oxide,



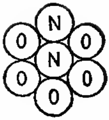
3. Nitrous Acid,



4. Hyponitric Acid,



5. Nitric Acid,



117. If the beginner has any difficulty in following the last statement, he may be helped by the following comparison: Let our copper penny piece, with its value 1, be taken to represent hydrogen, each coin standing for an atom. Let the shilling piece, in like manner, stand for carbon, whose combining proportion is 12 times greater than that of hydrogen. Suppose, then, that we throw into a bag shilling and penny pieces at random, purposely avoiding to notice how many of each we cast in. If we afterwards empty the bag, and ascertain the amount of money which it contains in each kind of coin, we shall certainly find the amount of copper money a multiple of 1—that is, one penny. There will be no halfpence, farthings, or mites—that is, no halves, fourths, or eighths, or other fractions of the original unit.

118. In like manner, the amount of silver coin will certainly be a multiple of twelve. We shall have silver equal to 24 pence, 48, 60, or some higher number; but it will be a multiple of 12. We can quite confidently predict that the number representing the amount of pence in the silver coin will be divisible by 12 without a remainder. So, in every compound containing hydrogen, the quantity of that element will be expressible, if not by 1, then by a multiple of 1. And the quantity of carbon in its compounds will be representable by 12, or a multiple of 12.

119. Lastly, the law of *compound* proportion could not fail to manifest itself according to the atomic view; for the aggregation of atoms does not alter their weight, and the atom is not divisible by the forces which effect chemical analysis, so that its weight should be shared among smaller particles. Had the atom been divisible, it might have been otherwise; and when two or more

atoms entered into combination, they might have broken up into lesser particles, among which the original weight was parcelled out.

120. According to the atomic theory, however, the atom is chemically indivisible; the combining proportion, therefore, or atomic weight of water, for example, is necessarily 18, because it consists of one atom of oxygen weighing 16, and two atoms of hydrogen, each weighing 1. The atomic weight of water is as necessarily 18, as the value of a penny and a shilling piece taken together is thirteenpence.

121. We have now learned two names representing the ratio in which each chemical substance unites with all others. Those were—*combining proportion* and *atomic weight.* The first is the best, as being the most expressive and least hypothetical of the two. The term atomic weight is shorter, and provided the student does not attach to it the character of absolute, but only of relative or chemical indivisibility, it may be employed in exactly the same sense as combining proportion. We do not hesitate to speak of an atom of water, and to state its atomic weight, although the so-called water-atom has never been isolated, and, moreover, is certainly divisible—namely, into particles of oxygen and hydrogen.

⁂ A series of coloured balls, with a different colour for each of the chief elements, will be found of service in illustrating the atomic theory. A white ball, for example, may represent an atom of oxygen, and a black ball one of hydrogen; whilst one of the former and two of the latter placed together represent a compound atom of water. A better device, however, is a set of cubes of wood, with the initial letters or symbols of the elements marked upon them. If the cubes are stained black, they may be lettered with chalk, and eight or twelve will be sufficient. They have the advantage over balls of standing securely, and admitting of being placed close together in vertical or horizontal rows. The letters also upon them are much more significant than colours, and they may be employed with great advantage to illustrate the nature and steps of all the chemical reactions which are discussed throughout this work. Each cube will admit of six *symbols*, or initial letters, being marked upon it, one on each face; but it is not advisable to letter more than one face of each cube.

CHEMICAL NOMENCLATURE.

122. The names or appellations by which the chemist distinguishes the various simple and compound substances are as much as possible constructed on a system, so as to supply information concerning the properties of the body; and if it be a compound, to tell the nature, and also the proportion, of its elements.

123. The nomenclature of chemistry is in this respect much superior to that of many of the other sciences, which give to everything they have to name a quite arbitrary title, so that the learner has first to make an effort of the memory to retain the term, and next, by a separate endeavour, to recollect what it denotes. Thus in mineralogy many substances are named in honour of individuals; and we read, accordingly, of Greenockite, Dolomite, Thomsonite, &c.—terms which give no information whatever concerning the nature and properties of the mineral.

124. Chemical nomenclature, notwithstanding, is defective, and will long remain so. Only a perfect knowledge of chemistry could secure a perfect nomenclature. In the meanwhile, our knowledge has outrun our skill in devising names, the system on which we set out at the beginning of this century having proved not nearly expansive enough to supply appellations for the multitude of unexpected new substances which have recently been discovered.

125. As names have been given to chemical substances since the earliest times, and long before chemistry became a science,

many bodies have several titles, although there is generally one preferred as the most scientific.

126. The rare and valuable metals, having attracted the attention of mankind from the remotest historical periods, have received names which are still to a great extent retained. The combustible constituent of oil of vitriol has the two names brimstone and sulphur. Most of the familiar salts have more than one title, as nitrate of potassium is called also nitre and saltpetre; sulphate of copper, bluestone and blue vitriol; sulphate of iron, copperas and green vitriol.

127. A few names have come down to us from the languages of the civilised nations of antiquity. The root, for example, of the word ammonia (spirits of hartshorn) is some thousand years old—Ammon, from which it is derived, having been the name of one of the gods worshipped by the ancient Egyptians, from whom the Romans transmitted the name to us.

128. In the ninth century the Arabians were the most distinguished chemists, and several of the names they introduced still survive. Many of them may be recognised by commencing with the Arabic definite article Al. Thus we have alcohol, alkali, alembic.

129. During the fifteenth and sixteenth centuries, the European alchemists were the most famous students of chemistry. We still retain many of their quaint, fanciful, but often expressive names; such as spirit of wine, spirit of hartshorn, spirit of salt, flowers of sulphur, aqua regia.

130. Astrology and alchemy went hand in hand, nor have we yet ceased to use some of the terms introduced by the astrological chemists. They associated the metal lead and the planet Saturn together, and we still speak of solutions of lead as Saturnine solutions. Nitrate of silver still bears the name of Lunar caustic, and crystallisations of silver are called the tree of Diana; silver and the moon (Luna or Diana) having been astrologically connected. In like manner, in unscientific works, one of the compounds of iron is still styled crocus Martis, in reference to the planet Mars, with which iron was associated.

The metal quicksilver is not likely soon to lose its astrological name of Mercury.

131. In the seventeenth century, the adoption of an erroneous theory of combustion led to the adoption of a nomenclature now totally abandoned. As none of its terms occur systematically in works of the present day, we say no more concerning it. Those, however, who wish to read works on chemistry published in the last century, many of which are of the greatest interest and importance, must make themselves acquainted with this nomenclature, which continued to be employed till the very close of the eighteenth century.

132. At that period the recognition of another theory of combustion, the discovery of many new gases, the detection of the composition of the air, and of that of water, revolutionised all chemistry, and led to the introduction of the nomenclature which we now employ.

133. It serves, upon the whole, very conveniently for the distinction of inorganic bodies from each other; but when we come to organic chemistry, we shall find that it has not proved sufficient to meet its wants.

34. The names of the elements we have given already. They are entirely arbitrary, and many of them were words of common language before they were adopted as scientific terms. In the case of the elements more recently discovered, an endeavour has been made to give names of similar termination to those which resemble each other. Thus all the metals discovered within this century have their names terminated in *um*, as potassium, sodium, lanthanum; and the names of all the metals terminate similarly, if their Latin appellations be used. Thus lead, in Latin, is *plumbum*, copper *cuprum*, antimony *stibium*, &c. With one exception, moreover (selenium), no element which is not a metal has its name terminated in *um*.

135. It is of importance to the student to remember this, and to notice that the table of elementary bodies is a list rather of Latin than of English names. The proof of this will be given in the next section.

136. Three of the elements, resembling each other in properties, and in several respects unlike the others, have their names ending in *on*—namely, carbon, boron, silicon. The latter is sometimes called silicium. The names of another remarkable group of elements end in *ine*—chlorine, bromine, iodine, and fluorine.

137. No community of property is intended to be represented by the termination in *gen*, common to oxygen, hydrogen, and nitrogen. Sulphur and phosphorus had received names long before our present system of nomenclature was devised; but these being distinctive and euphonious, and readily permitting adjectives to be derived from them, were willingly retained. The titles of the elements will be further considered in treating of each.

138. The names of compound bodies are as far as possible constructed so as to express their composition, and at the same time to indicate the class of compounds to which they belong.

139. With a view to this, compounds may be arranged into three divisions: *1st*, Binary compounds, or those which consist but of two elements—as water, of oxygen and hydrogen; common salt, of chlorine and sodium; vermilion, of sulphur and mercury. *2d*, Ternary compounds, which contain three elements—as marble, which consists of carbon, oxygen, and calcium; copperas, of sulphur, oxygen, and iron; nitre, of nitrogen, oxygen, and potassium. *3d*, Quaternary compounds, which contain four elements—as dry alum, which consists of sulphur, oxygen, aluminum, and potassium.

140. The chief binary compounds are those of the non-metallic elements, such as oxygen, sulphur, and chlorine with each other, or with the metals. Compounds of oxygen are called oxides, originally spelled *oxydes*. Thus red lead is a compound of lead and oxygen; it is termed by the chemist oxide of lead. Jeweller's putty consists of tin and oxygen; it is oxide of tin. Iron rust, in like manner, is oxide of iron.

141. Compounds of chlorine are termed chlorides. Common

salt, a combination of sodium and chlorine, is the chloride of sodium; calomel is the chloride of mercury; chloroform, the chloride of formyl.

142. Compounds of sulphur are called sulphurets or sulphides, and the latter term is now more generally used. Thus vermilion, consisting of sulphur and mercury, is the sulphuret or sulphide of mercury; king's yellow, consisting of sulphur and arsenic, is the sulphuret or sulphide of arsenic; galena is the sulphuret or sulphide of lead.

143. The names of the other non-metallic elements yield terminations in *ide*, like oxygen, or in *uret*, like sulphur. Thus the binary combinations of bromine, iodine, and fluorine are called bromides, iodides, and fluorides.

144. Nitrogen, carbon, boron, silicon, selenium, and phosphorus are said to form nitrurets or nitrides, carburets or carbides, borurets or borides, siliciurets or silicides, seleniurets or selenides, and phosphurets or phosphides of the element with which they combine. The latter term in each case is generally employed. Thus steel and cast-iron contain the carbide, and frequently also the silicide, of iron. The other names do not often require to be used.

145. When the non-metallic elements combine with each other, the term derived from oxygen, or from the body most like it, should go first; thus water is called the oxide of hydrogen. A compound of charcoal and sulphur is called the sulphuret or sulphide of carbon, not the carburet or carbide of sulphur. A compound of chlorine and sulphur, on the other hand, is not called the sulphuret or sulphide of chlorine, but the chloride of sulphur.

146. We have seen that the same elements combine in several proportions; we require, therefore, to distinguish different binary compounds of the same element from each other. Thus many metals combine with oxygen in several proportions. To distinguish them from each other, the Greek and Latin numerals are employed.

147. A combination of one combining proportion of another

body with one combining proportion of oxygen is called a *protoxide*, from the Greek πρωτος (*protos*), first.

148. To prevent confusion, however, the term protoxide is not used in its precise etymological meaning, to signify *first* oxide in the sense of lowest, or oxide containing the least quantity of oxygen. The title is restricted to oxides containing 16 parts, or one combining proportion of oxygen to one combining proportion or atom of the body united to it. Thus the black oxide of copper contains 63·5 parts of copper to 16 of oxygen; it is called the *protoxide*. The red oxide of the same metal consists of 127 parts of copper to 16 of oxygen; or for each combining proportion of copper there are only 8 parts, or half a combining proportion of oxygen. It is named the *suboxide*.

149. When the same body combines with oxygen to form a higher compound than the protoxide, the former is called the *deutoxide;* if there be a third, it is named the *tritoxide;* if a fourth, the *quadroxide;* but, for a reason to be mentioned presently, the last two terms are very rarely employed.

150. The term deutoxide signifies simply second oxide. Many deutoxides contain, however, twice as much oxygen as the protoxide. To indicate this, the Latin numeral is taken, and they are called *binoxides,* from *bis*, twice. Thus nitrous oxide or laughing-gas is the *suboxide* of nitrogen; the next oxide, or nitric oxide, is at once the deutoxide and the protoxide of nitrogen. The deutoxides of iron and of manganese are not *binoxides*. It is the third, or *tritoxide* of manganese which is its *binoxide*. A *sesquioxide* contains half as much oxygen again as a protoxide.

151. Similar prefixes are employed to indicate the proportion of the other non-metallic elements in their binary compounds. Thus calomel is the *protochloride* of mercury; corrosive sublimate, which contains twice as much chlorine, is the *deutochloride*, and at the same time the *bichloride* of mercury.

152. Iron pyrites is the *bisulphide* of iron; it contains twice as much sulphur as another mineral called the *proto-sulphide*.

153. In the same way we speak of *proto-iodides* and *bin-iodides* in reference to the compounds of iodine; *proto* and *bibromides* in relation to those of bromine; and so with the other non-metallic elements.

154. The highest binary compound of the same elements is frequently distinguished, not by a numerical prefix, but simply by the Latin particle *per*, which signifies, in combination, *highest* or *most intense.* Thus the black oxide of manganese is generally called the *peroxide*, not the binoxide.

155. Red oxide of iron, in like manner, is called the peroxide. Corrosive sublimate is frequently named the perchloride of mercury. So also we speak of periodides, persulphides, &c.

156. Oxides, which contain a large proportion of oxygen, generally exhibit acid properties. We shall afterwards particularly explain what an acid is, but in the meanwhile the sour taste which characterises the stronger ones, and is familiar to every one, may be accepted as the property marking a body to be an acid. Thus the oxides of sulphur, of arsenic, and of antimony, and the tritoxide and quadroxide of nitrogen, are all acids, and are named in relation to their acidity, so that we never see them distinguished by such terms as tritoxide and quadroxide.

157. Names are formed for these acid oxides, or, as they are more frequently called, oxygen acids (or oxyacids), by forming an adjective, ending in *ic*, from the noun representing the substance combined with oxygen, and in consequence acidified. Thus the quadroxide of manganese is called manganic acid; one of the oxides of the metal chromium, chromic acid; and one of sulphur, sulphuric acid.

158. It very frequently happens that there are more acid oxides than one of the same element. The binoxide of sulphur is an acid as well as the teroxide. When there are thus two acid oxides, the termination in *ic* is given to the one containing the greater amount of oxygen, and the lower oxide is denoted by an adjective ending in *ous*. Thus, whilst the teroxide of sulphur is sulphur*ic* acid, the binoxide is

sulphur*ous* acid. We have in like manner arsen*ic* acid, containing five combining proportions of oxygen to two of arsenic; arseni*ous* acid, containing three proportions of oxygen to the same amount of metal. So also we have nitric acid, with its five atoms of oxygen, and hyponitric acid with four; phosphoric acid and phosphorous acid; antimonic and antimonious, selenic and selenious acids.

159. When a body forms with oxygen more than two acids, the adjective endings which our language affords being exhausted, the terminations already mentioned, *ic* and *ous*, are qualified by prefixing to them the Greek prepositions *hyper*, signifying *over*, or *above*, or *more than;* and *hypo*, signifying *under*, or *less than*, to indicate the relation of the amount of oxygen in the new acid to that in those already furnished with names. Thus, after sulphurous acid had been named, a lower acid oxide was discovered, containing sulphur and oxygen in the proportion of atom to atom, so that it contains only half as much oxygen as sulphurous acid. This compound has been named *hyposulphurous* acid, to signify that it contains *less* oxygen *than* sulphurous acid.

160. In like manner an acid containing *less* oxygen *than* sulphuric, and more than sulphurous acid, is called *hyposulphuric* acid.

161. Those prefixes generally suffice; but where there are more than *four* acid oxides of the same element, as is the case with sulphur, peculiar and complex appellations require to be given. The compounds, however, necessitating such names are too rare to call for mention here.

162. The highest acid oxide is frequently distinguished simply by the prefix *per*. Thus we have perchloric, periodic, and permanganic acids.

163. Other binary compounds, besides oxides, are acids. To distinguish them from the oxygen acids, the name of the substance which replaces oxygen is made to form part of the adjective denoting the acid. Thus many of the binary compounds of hydrogen are acids; for example, its chloride, bromide, iodide, and fluoride. These, when spoken of as acids, are called

hydrochloric, hydrobromic, hydriodic, and hydrofluoric (and sometimes chlorhydric, bromhydric, iodhydric, and fluorhydric) acids.

164. The student must guard very carefully against confounding this class of acids, which are distinguished as the hydrogen acids, or hydracids, from the oxyacids. The caution is the more necessary, as the same substance often forms an acid both with hydrogen and oxygen. This is the case, for example, with sulphur. The oxyacid is called sulphuric acid; the hydracid hydrosulphuric acid. So also chlorine forms with oxygen chloric acid, with hydrogen hydrochloric acid; iodine with oxygen iodic acid, with hydrogen hydriodic acid.

165. Sulphur also, as well as hydrogen and oxygen, forms acids by combining with the other elements. These are distinguished by prefixing to the usual terminations in *ic* and *ous* the word *sulpho*, or *sulph*.

166. Thus a compound of three atoms of sulphur and two of arsenic is called sulpharsenious acid. Another sulphide of the same metal, containing two atoms more of sulphur, is called sulpharsenic acid. This may suffice for binary compounds.

167. The most important ternary compounds are the substances termed the oxysalts, being the compounds produced when oxygen acids unite with other oxides which are neither acids nor neutral bodies.

168. The oxides in question are distinguished by the name basic oxides (and are such bodies as soda, magnesia, and oxide of iron), so that an oxysalt is said to consist of an acid oxide and a basic oxide; or, more shortly, of an acid and a base. It will be afterwards stated, however, that other bodies act as bases besides the basic oxides. When sulphuric acid meets soda, it combines with it, forming Glauber's salt. When the same acid is added to magnesia, it forms Epsom salt. When it combines with oxide of iron, oxide of copper, and oxide of zinc, it forms the salts known familiarly as green, blue, and white vitriol.

169. All salts produced in this way result from the union of two binary compounds; but as each of the latter contains a

common constituent—namely, oxygen—after union, there are but three elements; for example, in the vitriols mentioned above, sulphur, oxygen, and the metal iron, copper, or zinc.

170. The oxysalts, therefore, are all ternary compounds, or combinations of three elements. They are named, however, as if the acid, though combined with, was yet distinct from, the basic oxide, or base in the salt.

171. Their nomenclature is very simple. If they contain an acid whose prefix terminates in *ic*, then the name of the salt containing the acid ends in *ate*. If, on the other hand, the affix of the acid ended in *ous*, then the name of the salt is terminated in *ite*. Thus salts containing sulphuric acid are called *sulphates*, those containing sulphurous acid *sulphites*: in like manner the salts of hyposulphurous acid are hyposulphites. So also nitric, phosphoric, and arsenic acids form nitrates, phosphates, and arseniates; and nitrous, phosphorous, and arsenious acids, nitrites, phosphites, and arsenites.

172. Acids containing hydrogen or sulphur instead of oxygen, have their last syllable or syllables modified in the same way, so as to supply names for the salts they form. Thus a salt consisting of hydrochloric acid and a base may be called a hydrochlorate, and one containing hydriodic acid a hydriodate. Combinations of sulpharsenious and sulpharsenic acid with bases are called sulpharsenites and sulpharseniates. There are peculiarities, however, connected with the hydrogen and sulphur acids which affect their nomenclature, and which will be specially referred to in an after part of the treatise. Thus a compound of hydrochloric acid and a base, such as soda, is called a chloride, known as chloride of sodium (common salt), whilst hydriodic acid and potash form the iodide of potassium.

173. The oxysalts are arranged into classes according to their acids. Thus we have phosphates, sulphates, nitrates, &c. They are divided into species according to the oxide they contain, and the species is marked by stating the name of the oxide, preceded by *of*. Thus the combinations which sulphuric acid forms with the oxide of iron, of copper, and of zinc respectively, are called

sulphate of the oxide of iron, sulphate of the oxide of copper, and sulphate of the oxide of zinc.

174. These names are often abbreviated. It is taken for granted that every one is aware that a sulphate containing a metal is constructed of that metal in the state of an oxide. In naming salts, accordingly, the words '*of the oxide*' are very frequently omitted, so that we say simply sulphate of iron, sulphate of zinc, sulphate of copper. So likewise Glauber's salt the sulphate of sodium, and stucco the sulphate of calcium.

175. The same acid frequently combines in more proportions than one with the same base. Numerical prefixes are then employed, similar to those made use of in the case of the binary compounds. Thus, besides the carbonate of sodium, we have another salt, containing twice as much carbonic acid. It is named the *bi*carbonate of sodium. In like manner we have the sulphate and bisulphate of potassium, the chromate, bichromate, and terchromate of potassium, and the oxalate, binoxalate, teroxalate, and quadroxalate of the same base. The other terms employed in speaking of salts will be explained when we have occasion to use them.

176. Quaternary compounds generally consist of two salts, which may contain the same acid, united together, and, where the acid is the same, the name of the common acid is stated only once, for brevity's sake. Thus dry alum, which is a compound of the sulphate of aluminum and the sulphate of potassium, is called simply sulphate of aluminum and potassium. The chloride of platinum combines with the chloride of potassium. The word chloride is used only once in the title of the compound salt—the chloride of platinum and potassium. More complex quaternary compounds, such as a combination of the chloride of gold with the bromide of potassium, can be distinguished only by lengthened appellations. They do not, however, often call for mention; and we shall find in the next section that complex combinations need not be named at all, but may be denoted in another and simpler manner.

CHEMICAL NOTATION.

177. The deficiencies of chemical nomenclature are happily supplied by what is called NOTATION, which bears the same relation to nomenclature that the Arabic ciphers, or Roman numerals, or algebraic signs, bear to written numbers. Thus a date of a year may be written down Eighteen hundred and sixty-six, or 1866, or MDCCCLXVI. In the same way we denote the most familiar of liquids by calling it water, or oxide of hydrogen, or by using the letters H_2O.

178. For this purpose each of the elementary bodies is indicated by one or two letters, which are called its symbol. When a single letter is employed, it is printed as a capital; when two are used, the second is printed small. The first of these is in every case (Tungsten excepted) the initial letter of the name of the element; but it is not the commencing letter of the English appellation, unless where that is identical with the Latin one. Thus the symbol of lead is not L, but Pb, from its Latin name plumbum; antimony is not An, but Sb, from stibium; and tin not T, but Sn, from the Latin stannum.

179. A great advantage is gained by this employment of Latin rather than English letters, as the same nomenclature is thus intelligible to all the civilised nations of the world who are acquainted with the ancient Roman tongue; and the English student, on his side, reaps the benefit of finding an old and familiar notation when he reads German, French, or other foreign works on chemistry.

180. As several of the elementary bodies begin with the same alphabetical letter, it is necessary to distinguish carefully their symbols from each other. Thus the names of no fewer than nine of the elements begin with C. To the most important of them, Carbon, the solitary initial letter is given as its symbol, whilst the others, as the table (par. 91) will shew, have, in addition to the common letter, a vowel or consonant to distinguish them. Thus, Calcium is Ca, Chlorine Cl. Great care must be taken not to confound the symbols. Thus, N_2O is laughing-gas; Na_2O, soda; SO_3 is sulphuric acid; SeO_3, selenic acid; SiO_2, silicic acid. The omission, or addition, or alteration, thus, of the secondary consonant or vowel, totally alters the meaning of the symbols as expressing the nature of a compound.

181. The symbol of a substance, when used alone, represents not merely that body, but a combining proportion, or atom of it. Thus, O stands for 16 parts, or one combining proportion of oxygen; N for 14 parts, or one combining proportion of nitrogen; Fe for 56 parts, or one atom of iron.

182. When more than one combining proportion or atom of a body requires to be expressed, it is done by placing a number to the *right* hand of the symbol. Thus, O_5 is five atoms of oxygen; C_3, three atoms of carbon; Fe_2, two atoms of iron. The number employed to multiply the symbol is, as shewn in the text, much smaller than the alphabetical letter, and is written at the upper or lower, generally at the lower, right-hand corner of the symbol.

183. When two symbols are placed side by side, they denote a compound of one atom of each ingredient—as, HCl, hydrochloric acid, a compound of hydrogen and chlorine; CO, carbonic oxide, a compound of carbon and oxygen; HgS, vermilion, constructed of mercury and sulphur.

184. When one of the associated symbols has a number placed to the *right* of it, the number multiplies *only* the symbol after which it is placed. Thus, N_2O_5, anhydrous nitric acid, signifies a compound of *two* combining proportions of nitrogen

and *five* of oxygen; the 2 multiplying only the N, or nitrogen, and the 5 multiplying only the O, or oxygen. H_2O, water, indicates a compound of *two* atoms of hydrogen and *one* of oxygen. Fe_2O_3, red oxide of iron, signifies a compound of *two* combining proportions of iron to *three* of oxygen; each symbol being affected only by the number placed to its right, or following it.

185. When a number, on the other hand, is placed before, or at the *left* hand of associated symbols, it multiplies *all* which follow it as far as the first comma, + (*plus*) sign, or full stop. To prevent confusion, the numbers placed to the left of symbols are generally made as large as the alphabetical letters they precede. Thus H_2O is water, a compound of two combining proportions of hydrogen and one of oxygen. $2H_2O$ is two atoms of water, or it is equal to H_2O,H_2O; $3N_2O_5$ is three atoms of anhydrous nitric acid; and $Fe_2O_3,3SO_3$ is persulphate of iron, a compound of one atom of red oxide of iron and three of sulphuric acid.

186. Symbols arranged together, as in the preceding illustrations, are called the formulæ of compounds, or chemical formulæ.

187. The term symbol, however, is not restricted to the elementary bodies, but is occasionally employed in the same sense as formula, but only in relation to the simpler combinations, such as binary compounds. Thus H_2O is as frequently termed the symbol as the formula for water, but the expressions for oxysalts and other combinations, which require at least three elementary symbols to denote them, are always called formulæ.

188. The two most important points to be attended to are, *first*, that in the formulæ of binary compounds the symbol of the metal or body *which least resembles* oxygen is written first or to the left. Thus oxide of iron is FeO, not OFe; sulphide of mercury is not SHg, but HgS; chloride of sodium is NaCl; and iodide of potassium KI.

189. *Second*, in the formulæ of oxysalts, the symbols of the

metal or basyl precede those of the acid, and it is now customary for the whole of the oxygen to be thrown together. Thus sulphate of sodium is Na_2SO_4 [previously NaO,SO_3]; carbonate of calcium, $CaCO_3$ [formerly CaO,CO_2]; nitrate of potassium, KNO_3 [previously KO,NO_5].

190. The reason why this apparently capricious inversion of the symbols is followed is, that the symbols represent Latin, not English words; and in arranging them into formulæ, a law of Latin grammatical construction is followed. Thus the symbol for oxide of iron, FeO, when written in full, becomes the words FERRI, *of iron*, OXIDUM, *oxide*, according to a familiar rule of Latin grammar, which teaches that when one noun governs another in the genitive, the genitive goes first. Fe, when taken alone, represents the nominative, FERRUM; but when associated with another symbol, it stands for FERRI, the genitive, which accordingly goes first.

191. Those who are unacquainted with Latin may accept as a safe and sufficient rule that, in arranging the symbols into formulæ, the former should be placed in exactly the reverse order of that which they would occupy if they were written as English words. Thus, in putting down the formula of the oxide, sulphide, chloride, bromide, iodide, or fluoride of a metal, the symbol of the metal goes first, and that of the non-metallic body follows it.

192. A similar remark applies to the formulæ of salts. Thus $FeSO_4$, the formula for sulphate of iron, stands for two Latin words, *ferri sulphas*—that is, *of iron, the sulphate;* so that again the English order is reversed.

193. In the case of the more complex combinations derived from plants and animals, the application of those laws is not so easy nor so evident, but it is followed as far as possible. Thus, gum, starch, sugar, and similar compounds, which consist of carbon, hydrogen, and oxygen, have the carbon expressed first, the hydrogen second, and the oxygen last. Acetic acid (the acid in vinegar), for example, is $C_2H_4O_2$.

194. The rules laid down are, with slight exceptions, followed

by the chemists of all countries, and the student should on no account wantonly or capriciously depart from them. It is not desirable to burden the memory by endeavouring to acquire at once a familiarity with the symbols and atomic weights or combining numbers of all the elementary bodies. It is quite enough if he learn the symbols and atomic or combining weights of each element and its compounds whilst he is studying it.

195. In class-rooms it will be found of great advantage to have a large table of the elements, their symbols and atomic weights, displayed at every chemical lesson; and the various decompositions illustrated by symbols in succeeding portions of this volume should be gone over, step by step, on the black board by the teacher, and the pupil made to exercise himself on the same subject with his slate.

⁂ The importance of familiarising even very youthful students of chemistry with chemical notation cannot be overrated. It should be taught, however, to beginners gradually, and rather indirectly than formally. By the constant employment of the symbols and formulæ in explaining chemical changes to a class, the pupils rapidly become familiar with their use, and soon prefer to have changes explained by means of them. A single lesson will never demand reference to a great number of formulæ; and if the signification of each is explained when it is shewn, the discussion of the first four elements will supply a sufficient number of examples to enable this chapter to be completely understood.

It should never be forgotten that chemical symbols are not like ciphers, mere substitutes for words, but are further supplements to them. Thus the symbols H_2O, CO_2, and $NaCl$, are not simply synonyms of water, carbonic acid, and chloride of sodium (common salt), but tell us the nature and relative amount of the elements of these bodies, which the words do not. The study of organic chemistry cannot be prosecuted without extensive reference to symbols; for the names, such as Chloroform, Creozote, Methyl, Napthalin, Glycocoll, &c., tell little or nothing of their nature. The chemist, in truth, should be as familiar with his symbols as the arithmetician with his ciphers.

LAW OF GASEOUS VOLUMES.

196. Several of the elementary bodies, and many of their most important compounds, are, at ordinary temperatures, gases, or may be converted into them by the application of heat.

197. Bodies which assume the condition of elastic fluids at such a temperature as 60° of Fahrenheit's thermometer, are generally distinguished as *gases*, whilst those which require a higher temperature to convert them into aërial fluids are called *vapours*. Thus, oxygen is called a gas, steam a vapour.

198. There is no distinction, however, of kind, but only one of degree, between a gas and a vapour. Each requires the addition of a certain amount of heat to it to make it an elastic fluid; and both, when deprived of that heat, become liquids or solids. A gas and a vapour, accordingly, differ from each other only in so far as the one requires a different amount of heat from the other to maintain it as an elastic fluid; otherwise they are identical. A vapour may be called an easily-condensed or temporary gas; a gas, a highly incondensible or permanent vapour. Gases and vapours shade away insensibly into each other, so that no sharp line of demarcation can be drawn between them.

199. The relation between atomic weight and atomic volume we are about to explain, applies equally to gases and to vapours. In stating it, however, we shall dispense frequently with the

word vapour, and call all elastic fluids gases, whether they are easy or difficult of condensation.

200. When the gases are taken in their combining proportions by weight, and examined as to the relative volumes they furnish, we do not find that each occupies a different space, as each has a different atomic weight; but with scarcely an exception, they all occupy the same space. A very simple relation subsists between the volumes they do occupy.

201. It is of practical importance to be acquainted with this, for it is a much more easy thing to measure out a certain volume of a gas, than it is to weigh accurately a required amount of it; and it is thus highly desirable to know what relation subsists between atomic weight and gaseous volume, so that we may be able to replace the difficult process of weighing by the more easy and accurate one of measuring.

202. Gases are measured in cylindrical glass vessels or jars, open at one end, and shut at the other, the sides of the jar being marked with lines, denoting how many cubic inches of gas the vessel can contain. When such a jar is used as a measure, it is filled with water or quicksilver, and placed standing with its mouth down in a basin or trough, containing the same liquid. The gas to be measured is then passed up through the water or quicksilver, which it displaces more or less, occupying its room, and filling, according to the amount of liquid displaced, a larger or smaller portion of the vessel. The number of cubic inches to which it amounts is then ascertained, by noting the figure marked upon the graduated jar, at the line where the gas and liquid meet.

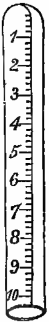


Fig. 1.

203. As gases expand or occupy a greater space when heated, and contract or fill a smaller one when cooled, it is necessary, when making comparative experiments, to examine each at the same temperature. A convenient one for this purpose is 60° Fahrenheit.

204. Gases alter their volume also when the pressure of the air changes, contracting into a smaller bulk when the pressure is

great, and occupying a greater one when it diminishes. The barometer is a measure of this pressure, and its alterations enable us to follow those which occur in the atmosphere.

205. The pressure of the air is greatest when it can support a column of mercury in the barometer 30 inches long, and diminutions in its amount are denoted by the column shortening to 29 or fewer inches. Comparative experiments as to the volume of gases require, accordingly, to be made with the barometer standing at the same height at each trial. The height generally taken is between 29 and 30 inches, but nearer the latter. We shall call it in round numbers 30.

206. At this settled temperature, then, of 60° Fahrenheit, and with the barometer standing at 30 inches, the volumes which combining or atomic weights of the gases occupy are ascertained. The relation which has been discovered will perhaps be best understood if explained a little in detail, as follows:

207. The atomic weights or combining proportions of each of the elements are supposed to be taken in grains; and, in the first place, one grain of hydrogen is accurately weighed and introduced into the graduated jar, so as to ascertain the space it occupies at the settled temperature and pressure. A glass stoppered bottle is then provided, exactly sufficient to contain the number of cubic inches to which the one grain of hydrogen amount.

208. A combining proportion of oxygen, or 16 grains, is then examined as to the space it occupies as a gas, and receiving it in the stoppered bottle previously emptied of the one grain of hydrogen, when it is found to fill exactly, without excess or deficiency, the vessel that the hydrogen filled. In other words, a bottle, jar, or other vessel, which, at a certain temperature and pressure, will exactly contain 1 grain of hydrogen, will, at the same temperature and pressure, contain neither more nor less than exactly 16 grains of oxygen.

209. In like manner, a combining proportion, or 35½ grains, of chlorine is found in the gaseous state to fill, without superfluity or deficiency, the same vessel which contained 1 grain

of hydrogen and 16 grains of oxygen. So also 100 parts by weight of oxygen, $6\frac{1}{4}$ of hydrogen, and 222 of chlorine, or any other quantities taken in the relative proportions indicated by their atomic weights, would, as gases, exactly fill vessels of the same capacity.

210. The atomic weights or combining proportions, then, of the three bodies mentioned, occupy, as gases, exactly the same space, or give equal volumes; so that, in experimenting, it will come to the same thing whether we weigh out the combining proportions of hydrogen, oxygen, and chlorine respectively, or measure out equal volumes of them as gases.

211. To point out the fact, that equal volumes of these bodies correspond to their atomic weights or combining proportions, we mark against each an outline square of the same size; thus:

Hydrogen, □ Oxygen, □ Chlorine, □

212. These combining measures have been determined by observing the volumes which the various elements occupy as gases or vapours when taken in their atomic proportions. Thus:

One Atom.				Cubic Inches.
1	grain hydrogen at 60° F. and 30 inches bar.			= 46·66
16	grains of oxygen	〃	〃	= 46·66
35·5	grains of chlorine	〃	〃	= 46·66
14	grains of nitrogen	〃	〃	= 46·66

213. From the above table it will be seen that if the volume or space occupied by an atom of hydrogen be considered 1, or □ (being 46·66), then the volume or space filled by an atom of oxygen will be also 1, or □ (being 46·66), and similarly with chlorine and nitrogen.

214. Following out these observations, Gerhardt has announced as a theory or hypothesis that equal volumes of the elementary substances in the gaseous condition, when compared under similar conditions of temperature and pressure, always contain the same number of atoms, and thus he reconciles the present

combining volume of the hydrogen class □ with the combining volume of all the other elementary substances.

215. The relations which subsist between the combining numbers or atomic weights and the combining volumes of the elementary substances may be better observed by comparing the specific gravity or density of a given volume of each, taking the volume of hydrogen as unity, when it will be found that an equal volume of the various elements, in the form of gas or vapour, contains a quantity of each element, which accords closely with the combining numbers:

	Combining Number or Atomic Weight.	Specific Gravity. Hydrogen = 1.
Hydrogen	1	1·000
Oxygen	16	15·936
Sulphur	32	31·705
Chlorine	35·5	34·940
Bromine	80	79·806
Iodine	127	125·607
Nitrogen	14	13·969
Mercury	200	201·110

216. Again, the atomic volume of substances may be determined by dividing the combining proportion by the specific gravity. Thus, the atomic or combining weight of oxygen is 16·00, and if this be divided by the specific gravity of oxygen, 1·106, we obtain the atomic or combining volume of 14·46; whilst if the atomic or combining weight of hydrogen, which is 1·00, is divided by 0·0693, which is the specific gravity of hydrogen, we obtain 14·43 as the combining measure of hydrogen. The following table will exhibit this point more clearly:

	Specific Gravity.	Combining Weight.	Combining Volume.
Oxygen	1·106	16	14·46
Hydrogen	0·0693	1	14·43
Nitrogen	0·972	14	14·37
Chlorine	2·470	35·5	14·33

217. It will thus be observed, from the above calculated

examples, which are only a few of those which might be given, that oxygen, hydrogen, nitrogen, and chlorine have a similar combining volume (nearly 14½), and may therefore be represented by a similar and single volume or square □.

218. From the above table, it will be apparent that the same volume of the elements will contain an atomic or combining proportion by weight of each, and, conversely, that the atomic or combining proportion of each of the elements will occupy the same space or volume. If hydrogen be taken as unity, and its combining volume be represented by 1, or □, then an atomic or combining proportion by weight of every other elementary body should also give an atomic or combining volume of 1, or □. The following table will illustrate this:

	Symbol.	Atomic Weight.	Atomic Volume.
Hydrogen	H	1	1 or □
Oxygen	O	16	1 or □
Sulphur	S	32	1 or □
Chlorine	Cl	35·5	1 or □
Bromine	Br	80	1 or □
Iodine	I	127	1 or □
Nitrogen	N	14	1 or □
Mercury	Hg	200	1 or □

219. It will therefore be apparent that, taking the system of combining proportions, and the present notation employed in this treatise, the combining proportion of hydrogen is regarded as 1, or unity, either by weight or by volume; and that the 14 grains of nitrogen, 35½ grains of chlorine, 127 grains of iodine, 80 grains of bromine, and 19 grains of fluorine—that is, the combining proportions in grains of those bodies—occupy the same space, as gases, as one grain of hydrogen.

220. If we wish to combine the bodies last mentioned in single combining proportions with each other, we take them in equal volumes. Thus, to form hydrochloric acid, we take any volume of chlorine, and mingle it with the same volume of hydrogen.

The result is the same as if we had weighed $35\frac{1}{2}$ parts of the chlorine for every single part of the hydrogen.

221. No elementary substance yields a greater volume than hydrogen, but the compound gases and vapours give one twice as great as that of this gas. They have, accordingly, placed after them a double square ◫, which has twice the capacity of that of the simple or elementary substances.

222. One important body appears to present an exception to this remark—an equivalent (32 parts by weight) of sulphur, when in the gaseous state, at the temperature of 900°, occupies a space three times *less* than that filled by the combining proportion of hydrogen; but at 1900° it occupies the *same* space as the combining proportion of hydrogen. Phosphorus and arsenic, when taken in their combining weights, only occupy a space one half of that of hydrogen, and are apparently exceptions to the rule, but it is probable that, as in the case of sulphur, further investigations will remove these exceptions.

223. When gases combine with each other, they sometimes unite without any change of volume occurring. In this case their combining measure is the sum of the combining measures of their components. Thus combining proportions of hydrochloric, hydrobromic, hydriodic, and hydrofluoric acids, occupy a space, as gases, twice greater than the combining proportion of hydrogen, because each of them contains an atom of hydrogen along with one of chlorine, bromine, iodine, or fluorine, all of which have a combining measure equal to that of hydrogen.

224. In the great majority of cases, however, condensation occurs, or the volume is lessened when gases combine; thus, two volumes of hydrogen, for example, and one volume of oxygen, form only two volumes of steam; or water as a gas occupies the same space as the hydrogen in it would fill if it were free.

225. One volume of nitrogen and three of hydrogen form two volumes of gaseous ammonia, or contraction occurs to the extent of two volumes; in other words, the compound gas occupies only half the space its elements occupied before combination;

and one volume of carbon vapour (hypothetical) and four volumes of hydrogen form only two volumes of marsh gas, and thus the five separate volumes become condensed into two volumes.

226. The contractions which do occur are simple, however, as in the examples given. Diminutions in volume to the extent of fractions of its original bulk never occur, so that the combining measures of the compound gases are exactly those of the elementary bodies, or are multiples of them.

227. The vapours of organic substances afford examples of both classes. No organic substance yields a vapour less than that of hydrogen or one volume. The organic substances which play the part of simple bodies, and thus combine together, or with other substances, like elementary bodies, have a combining volume similar to that of hydrogen, namely, 1 or □, and an example of this class is ordinary ether; whilst other organic substances, which conduct themselves like compounds, such as hydrochloric acid, have a double combining volume, namely, 2 or □□; and an illustration of this group is the vapour of alcohol.

228. The volume which the combining weight of a gas occupies is generally called the combining measure of the gas. It may also be named its atomic or combining volume.

229. These terms all express the fact, that the combining proportion or atom of every gas occupies, as an elastic fluid, a certain constant volume, so that gases measured out according to those volumes will be found to present themselves in exactly the same relative proportions by weight, as if they had been weighed out according to their combining weights. A given volume of hydrogen always weighs exactly sixteen times less than an equal volume of oxygen; whilst 127 grains of iodine, when examined in a gaseous state, and proper allowance is made for temperature and pressure, occupy no greater space than one grain of hydrogen. The measurement of gases, accordingly, may often be advantageously substituted for the weighing of them.

230. In order to indicate the difference between the combining measures of the simple and those of the compound gases and vapours, we subjoin a short table of some of the more important. They will be denoted throughout the book by the squares already described:

Gas.	Symbol.	Combining or Atomic Weight.	Combining or Atomic Measure.
Hydrogen	H	1	□ or 1
Oxygen	O	16	□ or 1
Nitrogen	N	14	□ or 1
Chlorine	Cl	35·5	□ or 1
Water	H_2O	18	□□ or 2
Carbonic Acid	CO_2	44	□□ or 2
Nitric Oxide	NO	30	□□ or 2
Ammonia, gaseous	NH_3	17	□□ or 2
Hydrochloric Acid	HCl	36·5	□□ or 2
Ether Vapour (a double atom or molecule)	$\left.\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\right\}O$	74	□□ or 2
Alcohol Vapour	C_2H_6O	46	□□ or 2
Marsh Gas	CH_4	16	□□ or 2
Olefiant Gas	CH_2	14	□□ or 2
Acetic Acid	$C_2H_4O_2$	60	□□ or 2
Chloroform	$CHCl_3$	48·5	□□ or 2

231. The chief point to which the student should attend is, that the numbers expressing combining measures count from hydrogen as unity, as is the case with combining weights.

INORGANIC CHEMISTRY.

232. The discussion of the laws of chemistry is followed by a consideration of each of the more important elements in turn, and of its chief compounds. The latter are arranged in two great divisions—that, namely, of organic, and that of inorganic chemistry.

233. Organic chemistry may in the meanwhile be defined to be the chemistry of plants and animals, and of the substances directly and indirectly derived from them. A fuller definition is given in the section which treats of this department of the science.

234. Inorganic chemistry is best defined negatively, as that section of the science which considers the properties of those substances which are not of vegetable or animal origin. We commence with inorganic chemistry, in connection with the discussion of the elements.

OXYGEN.

Combining weight, 16; *symbol*, O; *density*, 1·1056 (*air*, 1·000);
combining measure or volume, 1 *or* □
[*Old combining or atomic weight*, 8; *symbol*, O.]

235. At all observed temperatures, oxygen, when uncombined, is a gas. It is the most widely diffused body in nature,

forming one-fifth part of atmospheric air by volume, and eight-ninths of water by weight, besides being a constituent of nearly all the earths and rocks of the globe. It is estimated to form nearly one-half of our planet, and more than one-half of living plants and animals.

236. Its name is derived from the Greek ὀξὺς (oxys), acid, and γενναω (gennao), I call into being, or give rise to—in allusion to its property of forming acids, by combining with other elementary bodies. The word oxygen thus signifies the *acid-producer*, and was given to this element at a time when all acids were believed to contain oxygen, and to owe their acidity to its presence. We now know many acids, such as hydrochloric, which contain no oxygen, and we do not impute the acidity of those which possess it, to its occurrence in them. We retain the name, therefore, simply as a convenient appellation for this important substance.

237. *Preparation.*—Oxygen is generally disengaged from some oxide or salt containing it, by the application of heat. On the small scale, the oxide made use of is the red oxide of mercury, HgO. To prepare oxygen from it, let a few grains be placed in a test-tube, and the tube held in the hand, or in a convenient tube-holder (fig. 2), exposed to the heat of a spirit-lamp. The oxide, HgO, becomes nearly black, and at a temperature of 700° to 800° F. it separates into its two constituents, mercury or quicksilver, Hg, and oxygen, O. The former rises in the tube as vapour, till it reaches a cool portion of it, where it condenses in its characteristic form of brilliant silvery globules. The oxygen passes away as a colourless, invisible gas, but its presence may be proved by thrusting into

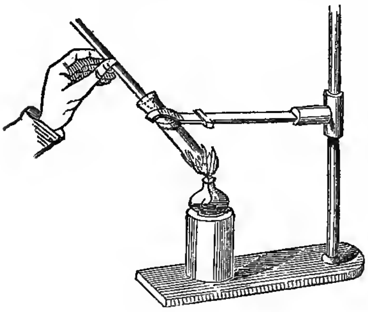


Fig. 2.

the tube a wooden match with a red-hot tip, which will immediately burst into full flame.

238. The oxide of mercury yields less than 8 per cent. of its weight of oxygen, and the process is costly when a large quantity of gas is required; but it deserves the student's special attention, owing to the simplicity of the decomposition which leads to the evolution of the gas, and because it is the first substance from which oxygen was obtained—namely, in 1774, by Dr Priestley.

239. The salt most suitable for the preparation of oxygen is the chlorate of potassium, $KClO_3$, a substance largely consumed in the arts, and easily procured. To prepare oxygen from it, a few grains may be placed in a test-tube (fig. 2), and the flame of a spirit-lamp applied. The salt quickly melts, and becomes, although quite free from water, a clear liquid. It then begins to effervesce, in consequence of the bubbling through it of bells of oxygen, O, and this continues till the whole of the oxygen is disengaged, and chloride of potassium, KCl, is alone left in the tube. If a red-hot match be plunged into the tube whilst the melted chlorate of potassium is effervescing briskly, it will burst into full flame. Chlorate of potassium yields more than one-third of its weight of oxygen, and one ounce of the crystals evolves 500 cubic inches (nearly two gallons) of the gas.

240. When oxygen is wished in large quantity, a retort is substituted for the test-tube, and the gas is collected in jars at the pneumatic trough. The chlorate of potassium is employed as the source of the oxygen, but it is previously mixed with from one-third to one-fifth of its weight of the black oxide of manganese, red oxide of iron, or black oxide of copper, which have a remarkable power of increasing (in a way not easily explained) the rapidity with which chlorate of potassium evolves oxygen, by admitting of the salt being decomposed at a much lower temperature, or from 450° to 500° F.

241. The pneumatic trough referred to (fig. 3), is a box made of wood or sheet-metal, generally about two feet long, a foot and a half in breadth, and a foot in depth; but it may be

made of any size. At one side, parallel to the length of the trough, a shelf, A, is fixed about two inches below the edge of the box. Holes are bored in this shelf at short distances, in order to allow gas to be passed into jars, standing on it with their mouths over the apertures. A movable stool, B, stands within the trough, of such breadth as nearly to fill the space between the free edge of the shelf at the one side, and the wall of the trough on the other, and of such height, that its upper surface is exactly on a level with that of the shelf. This stool has an aperture in the centre of its upper surface, which forms the termination of a funnel-shaped cavity hollowed out in the wood, so that its wider mouth looks downwards, and the aperture already referred to corresponds to the end of the pipe of the funnel, and points upwards. A spout, C, projects from one extremity of the trough about one inch above the level of the shelf. It serves to carry off the excess of water discharged from the jars as they are filled with gas. A smaller trough is placed permanently to receive the water which runs off. Such an arrangement is rendered necessary by the fact, that at the beginning of any process for collecting gas at the pneumatic trough, all, or the greater number, of the jars which are to be filled with the elastic fluid must be arranged full of water on the shelf, whilst at the end of the process the whole of the jars are emptied of water, and the trough which receives it would run over, if the spout and smaller reservoir were not provided for its reception.

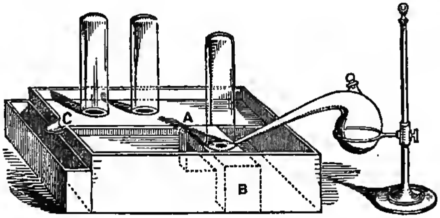


Fig. 3.

242. In using the pneumatic trough, water is poured in till it reaches the level of the spout, and begins to flow over. The jars in which the gas is to be collected, and which may be of various shapes and sizes, as shewn in figs. 3 and 4, are filled with water by plunging them obliquely with their shut ends downwards into the cavity, or, as it is called, the well of the trough. When full of water, they are inverted, so as to have their open mouths downwards, and are lifted, or rather slid, on to the shelf, where they stand till each in its turn is about to be filled with gas. If so much water be removed from the well of the trough in filling the jars that it sinks to the level of the shelf, then the trough must be replenished with water; for the jars cannot be kept full of liquid unless their mouths are below the surface of the water, and a column of about an inch in height should be left above the shelf. If this be neglected, in the rapid transference of jars to and from the shelf, air will certainly be allowed to enter, and the collection of gas arrested till the jar is filled with water anew.

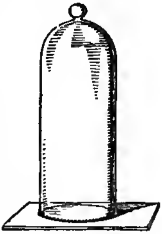


Fig. 4.

243. In the preparation of oxygen, the mixture of chlorate of potassium and oxide of manganese is placed in the bulb of a retort (fig. 5), in quantity sufficient to fill it one-half or less, the stopper A is tightly fixed in, and the beak B or extremity of the long tube of the retort plunged below the surface of the

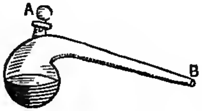


Fig. 5.

Fig. 6.

Fig. 7.

water in the trough (fig. 3). Instead of a retort, a flask (fig. 6) may be used, furnished with a bent tube, passed through a cork, which fits the neck of the flask. The movable stool is then pushed along till it stands over the beak of the retort. Heat is now applied to the retort or flask by means of a spirit-lamp (fig. 7), a gas flame, or a small furnace or choffer containing coal or charcoal, the retort or flask being supported on one of the rings of a retort-stand (fig. 8). The first effect of the application of heat is to expand and expel the air in the retort, which comes bubbling up through the aperture in the stool, and is allowed to escape. When the pure gas succeeds it, one of the jars full of water standing on the shelf is transferred from it to the stool, its mouth being kept under water during the transference. The gas now rises into the jar, causing the water to descend till it has expelled the whole of it. The jar, when filled, is slid back again to the shelf, and another full of water removed to the stool, and this manipulation is repeated till all the jars are filled with gas, or the latter ceases to be evolved.

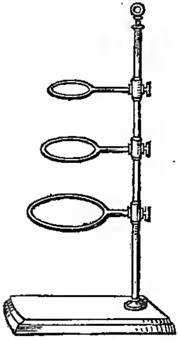


Fig. 8.

244. When the contents of a jar are to be examined, it is removed altogether from the trough, by sliding it off the shelf on to a gas tray, as it is called. This consists of japanned tin plate, or sheet-zinc, and exactly corresponds in shape to the cover of a cylindrical canister or the lid of a round snuff-box. This tray is filled with water, and the jar, with its mouth down, being transferred to it, the two are lifted off together, the tray being held in one hand, and the other laid on the shut end of the jar to keep it from falling over. A jar of gas may be kept apart for any length of time, provided only the tray be kept full of water. If the mouths of the jars are ground, squares or disks of plate-glass which fit air-tight will be found still more convenient than the gas trays.

245. When the gas is to be examined, as, for example, by

plunging a lighted candle into it, the jar is quickly inverted, and the tray lifted off. In doing this, the jar should be held above the pneumatic trough, so as to allow the water which runs out of the tray to be received by it, and prevent it wetting surrounding objects.

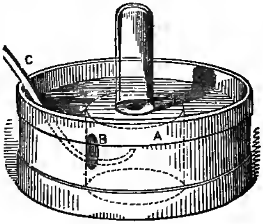


Fig. 9.

246. Other gases are collected at the pneumatic trough in the same way as oxygen. If, however, a gas be very soluble in water, that liquid must be dispensed with, and mercury employed in its place. We accordingly distinguish two varieties of the pneumatic trough—the water and mercurial. Troughs are also constructed of stoneware, and have the advantage of being cleanly and water-tight. The wood-cut (fig. 9) represents one, with a stoneware stand, A, for the jars, and a lateral aperture, B, for the beak of the retort or tube, C, delivering the gas. A tub, a wash-hand basin, a foot-pail, a leaden cistern or sink, or any other water-tight box, may be used as a pneumatic trough, with a couple of bricks or flat stones to support the jars.

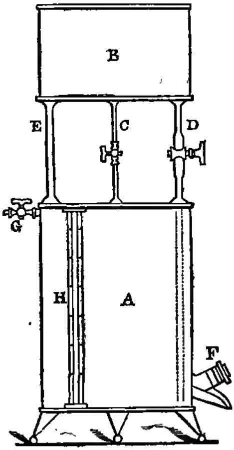


Fig. 10.

247. Besides the pneumatic trough, with its glass jars, it is desirable to have vessels of larger capacity, in which considerable quantities of gas can be collected, and from which it can be drawn off at pleasure. Such vessels are called gas-holders, or gasometers, and are constructed of tin plate, or, better, of zinc or copper. The figure (fig. 10) represents one of the most convenient, distinguished by its inventor's name, as Pepys' gas-holder. A is a metallic drum or cylinder; B a large funnel, communicating with A by a small tube C, which

terminates in the roof of the cylinder, and a large one, D, which descends to nearly the bottom; E is a pillar of support to the funnel; F is a tube placed at an angle with the cylinder, and provided with a nut which screws into its mouth, and fits it air-tight; G is a stop-cock, projecting laterally from the top of the cylinder.

248. In the figure the gas-holder is represented in the condition in which it would ordinarily be called empty—in other words, full of air. As a preliminary step to filling it with gas, water is poured into the funnel B. It descends by the tube D, and partly by C, whilst the air escapes by C and G. When water runs out at G, the cylinder is full, and all the stop-cocks are shut. The nut of the oblique tube, F, is then unscrewed, and the beak of the retort, or exit tube of the flask, from which the gas is issuing, is inserted through F, and pushed in till its end is fairly within the cylinder. The gas rising vertically, accumulates in A, whilst the water it displaces flows out at F, past the neck of the retort or tube of the flask. When the water is all expelled, the retort or flask is withdrawn, and F closed again with the nut. A glass tube or gauge, H, communicating at each end with the cylinder, and in which the water stands at the same level as in A, allows the amount of gas in the latter to be readily observed.

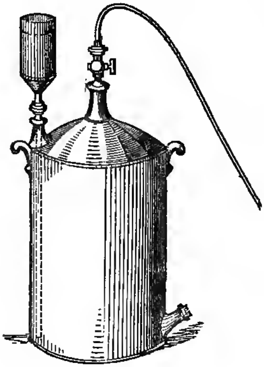


Fig. 11.

249. The gas is drawn off either by C or by G. If a jar is to be filled, water is poured into B, and the jar full of water is placed mouth downwards over C. C and D are then opened, and the water which descends by D expels the gas by C. If a current of gas is wished, as for the lime-ball light or the oxyhydrogen blowpipe, the tube to convey it is attached to the end of G. B is kept full of water, and when D and G are opened, the gas rushes out by the latter.

250. A cheaper gas-holder, made of stoneware, is represented by fig. 11. It is filled with oxygen in the manner described above, and thereafter, when the gas is desired to be taken out, water is poured in by the funnel, which thus descends to the bottom of the gas-holder, and presses the gas out. Gas bags, made of vulcanised caoutchouc cloth, and provided with stop-cocks, are likewise employed for the storage and transport of gas.

251. When required in large quantity, oxygen may be cheaply prepared by placing black oxide of manganese, MnO_2, in an iron bottle or gun barrel, and heating in a furnace; or by passing the vapour of hydrated sulphuric acid (oil of vitriol), H_2SO_4, over red-hot platinum, when the sulphuric acid, SO_3, is resolved into sulphurous acid, SO_2, and oxygen, O. The gas may also be prepared by heating oxide of barium, BaO, in contact with atmospheric air, when it becomes binoxide of barium, BaO_2, and on further heating is resolved once again into oxide of barium, BaO, and oxygen, O, which escapes as gas.

252. Oxygen may likewise be obtained by strongly heating the nitrates of potassium, sodium, and barium, the chloride of lime (bleaching-powder), and the higher oxides of the metals, such as the red oxide of lead. A process for the preparation of the gas in the cold is to act upon a mixture of peroxide of barium and bichromate of potassium by sulphuric acid. The apparatus employed is a gas bottle (fig. 12), into which the mixed powder is put, and the sulphuric acid is poured down the funnel tube. The oxygen readily comes away, and may be collected at the pneumatic trough in the ordinary way.

Fig. 12.

253. *Properties.*—Oxygen has no colour, odour, or taste. It is heavier than air, in the proportion of 1·10563 to 1·000. One hundred cubic inches of oxygen at 60° F. and 30 inches bar. weigh 34·203 grains. It cannot be liquefied or solidified when uncombined. It is

soluble in water to the extent of 3 cubic inches of oxygen in 100 of water at 60° F., and 4 cubic inches of the gas in 100 of water at 32° F. This is a slight solubility; nevertheless, it is of great importance to water-animals, the greater number of which are dependent on this dissolved oxygen for the support of respiration and life. Fishes die if placed in water which contains no oxygen in solution. The sea and other natural beds of water dissolve this gas from the atmosphere.

254. Oxygen has the power of uniting with every other elementary substance excepting fluorine, and, indeed, it forms two or more compounds with the majority of the simple substances or elements. The most striking property which it possesses is its power of supporting and enlivening combustion. In illustration of this, the following experiments may be tried:

255. *1st*, Kindle a match of wood, and blow it out, leaving the end red-hot. Plunge it into a jar of oxygen, when it will burst into bright flame. Withdraw it immediately, blow it out, and introduce it a second time into the gas. It will be kindled afresh; and if the gas be pure, a splinter of wood may be blown out and rekindled twelve, fourteen, or twenty times, according to the size of the jar. A wax or tallow candle will exhibit the same phenomenon, but it is difficult, in extinguishing a wax light, to retain the wick red-hot.

256. *2d*, Place a piece of roll sulphur in a small tin cup, on a pedestal standing on a plate, and set it on fire by touching it with a red-hot wire. When it has begun to burn, invert over it a pretty large jar or globe of oxygen (see fig. 26). The sulphur immediately bursts into fuller combustion, burning with a rich purple-blue flame, and evolving a much intenser heat than when burned in common air.

Fig. 13.

257. *3d*, Dry carefully a piece of phosphorus about the size of a split pea. It is to be deprived of adhering moisture by gently pressing it between folds of blotting-paper, friction being as much as possible avoided, as it may kindle the phosphorus, and occasion

a severe burn to the experimenter. The phosphorus is then to be placed in a small metallic cup attached to a wire (fig. 13), and after it has been inflamed by touching it with a hot wire, it is to be introduced into a glass globe, or other convenient jar, filled with oxygen (fig. 14). It burns with a brilliancy so intense, that the eye cannot bear it. The heat evolved is also very great, and frequently occasions fracture of the vessel in which the experiment is made. To guard against this, care should be taken that the phosphorus is dry, otherwise it spirts, and portions of it, in a state of combustion, are projected against the sides of the vessel, and occasion its destruction. Some water should always be left, or placed at the bottom of the glass vessel, to receive any phosphorus which may boil over, and the vessel itself should be of considerable dimensions, so that the burning combustible may be at some distance from its sides. An experiment similar to that recorded above may be made with wood-charcoal, a fragment of which, after being well kindled, is to be suspended by a wire in a jar of oxygen. A charred cork burns in these circumstances very prettily.

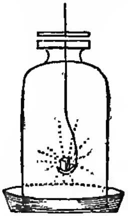


Fig. 14.

258. *4th*, The most brilliant of all the experiments on combustion in oxygen is that with iron wire. For its performance a glass vessel is needed, resembling a large stoppered bottle without a bottom. A stopper is placed in the neck of the bottomless jar, and it is filled at the pneumatic trough with oxygen in the usual manner, and removed from it on a gas tray. A bundle of the thinnest iron wire, such as is sold under the name of harpsichord wire, is formed into a spiral, as large in diameter as the neck of the jar will allow to enter easily. This is done by coiling the wire round a cylinder of the proper dimensions. The thickness of the spiral must be varied according to the size of the jar. For one which will contain 200 cubic inches of gas, it may be of the thickness of the cord used for wrapping quills. One end of the spiral is

tipped with brimstone, by heating it, and immersing it in flowers of sulphur till a small portion of the latter adheres to it. The other end of the spiral is fixed into a cork, which fits the neck of the bottomless jar. The sulphur having been kindled, the stopper of the jar is quickly withdrawn, and the spiral inserted, the cork to which it is fixed being firmly pressed down, so as to close the mouth of the jar (fig. 15). The sulphur bursts into full flame, and kindles the iron, which in its turn burns with great brilliancy, evolving a bright light, and letting white-hot drops of fused oxide of iron fall into an iron tray placed below. A similar experiment may be observed with zinc foil, which, when tipped with sulphur, and set fire to, burns with a brilliant bluish-white flame. These, and the other experiments on combustion described, are seen to greatest advantage when performed in a dark room.

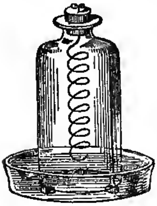


Fig. 15.

259. Combustion in oxygen and in atmospheric air is essentially the same phenomenon—air consisting of oxygen diluted by four times its volume of the negative gas nitrogen. Combustion, however, as might be expected, is much slower, and less brilliant, in atmospheric air, one-fifth part of which only is oxygen. Otherwise, the phenomena presented by bodies burning in air, and in oxygen, differ only in degree, and not in kind. A combustible gives out an intenser heat and light in the pure gas than in the diluted one, but it evolves the same *quantity*, at least of heat, in both cases—that is, the same weight of ice will be melted during the combustion of twelve pounds of charcoal and thirty-two pounds of oxygen, whether the oxygen be supplied pure, or be furnished in the state of dilution in which it occurs in atmospheric air. In the first case, however, the charcoal will burn a great deal more rapidly, and in so doing will produce a much higher temperature than when burning more slowly in air. The quantity of heat evolved will be exactly the same; for although the charcoal burned in oxygen will melt ice much more rapidly than the charcoal burned in

air, the former will not melt a greater weight of ice than the latter.

260. During combustion, an oxide of the combustible is invariably formed. Thus the iron wire in the last experiment unites with the oxygen to form the black or magnetic oxide of iron, Fe_3O_4. Phosphorus forms anhydrous phosphoric acid, or phosphoric anhydride, P_2O_5. Sulphur produces sulphurous acid, or sulphurous anhydride, SO_2. Charcoal forms carbonic acid, or carbonic anhydride, CO_2. A match or candle contains two combustibles—carbon, C, and hydrogen, H; the former is oxidised into carbonic acid, CO_2, the latter into water, H_2O.

261. We are unable to explain the cause of the evolution of heat and light which accompanies oxidation. In the great majority of cases where chemical combination occurs, heat and light are evolved, whether oxygen be one of the combining bodies or not; so that production of a high temperature, and the development of light, appear to accompany all cases of intense chemical combination. There is nothing, therefore, peculiar, so far as theory is concerned, in the combustion of bodies in oxygen; but as it is the substance by means of which we burn the fuel occurring at the earth's surface, and thereby provide ourselves at will with artificial heat and light, the relation of oxygen to combustion is more important than that of any other body.

262. Substances which, by combination with the marked combustibles—such as charcoal, sulphur, phosphorus, and the metals—cause the evolution of heat and light, are called *supporters of combustion.* Thus, in our ordinary fire-places, the carbon and hydrogen of the coal are the combustibles, and the oxygen of atmospheric air supports their combustion.

263. The compounds of oxygen are divided into three classes: 1*st*, *Neutral oxides*—such as water, H_2O; carbonic oxide, CO; nitrous oxide, N_2O—which do not possess a sour taste; do not change the tints of colouring matters; and do not combine with acids, or with bases to form salts. The student can verify those properties with water.

264. 2*d*, *Acid oxides*, which have a sour taste; change vegetable blues to red, and vegetable browns to yellow; and form salts by combining with bases. To observe those properties, nitric acid, HNO_3, or sulphuric acid, H_2SO_4, may be taken, but the acid must be diluted before it is tasted. To make manifest its action on colouring matter, an infusion must be made of the purple cabbage, or of the colouring matter, *litmus*, which can be procured from any druggist. The purple-blue liquids so prepared, are at once changed to red by a very small addition of the acids referred to. Solutions of brown colouring matter are prepared by pouring hot water on powdered turmeric, or medicinal rhubarb, and adding to the yellow liquid so procured a little carbonate of sodium, which renders it brown. The acid will then change it back to yellow. To observe the third character, caustic soda, NaHO, one of the most powerful bases, may be added to sulphuric acid, H_2SO_4, or caustic potass, KHO, to nitric acid, HNO_3, till in either case the acid loses its sour taste. The liquids are then evaporated, and yield Glauber's salt—the sulphate of sodium, Na_2SO_4, in the one case, and saltpetre, the nitrate of potassium, KNO_3, in the other.

265. 3*d*, *Basic oxides*, which in the best marked examples have a soapy taste, as seen in caustic potass, KHO, and caustic soda, NaHO, change vegetable reds to blue or to green, and yellows to brown, exactly reversing the effects of acids; and form salts by combining with acids. Only a few of the bases have a taste, or action upon colouring matter; all of them, however, possess the third character. Their action on colouring matter may be observed by adding a solution of potass, soda, or lime-water to an acidified, and therefore red, infusion of cabbage or litmus; when its colour changes to green in the first case, and to blue in the second. If these basic oxides are added to infusion of turmeric or rhubarb, it is at once changed from yellow to brown.*

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* Several of the acid oxides, such as silicic acid, SiO_2, and the majority of the basic oxides, as oxide of iron, Fe_2O_3, are tasteless, and without action on

HYDROGEN.

Combining weight, 1; *symbol*, H; *density*, 0·0692; *combining measure, one volume or* □

266. *Distribution.*—Hydrogen does not exist uncombined in nature, but is one of the elements of water, and is a constituent of all plants and animals, of nearly every compound combustible, and of the great majority of organic bodies. Its name is derived from ὕδωρ (hydor), water, and γενναω, I generate, so that it signifies the 'water-producer.' Hydrogen forms one-ninth part by weight of all water.

267. *Preparation.*—Hydrogen is generally obtained from water, its principal oxide, H_2O; but frequently also from hydrochloric acid, its chloride, HCl. The simplest mode of preparing hydrogen is by sending a galvanic current through water, H_2O, when it suffers resolution into its two constituent gases, oxygen, O, and hydrogen, H, which may be collected separately.

268. Another method—interesting from the simplicity of the change which occurs, but much too costly to be employed in practice on the large scale—is to fold up a fragment, about the size of a pea, of the metal potassium in blotting-paper, and pass it rapidly under the edge of a gas jar standing full of water on the shelf of the pneumatic trough. The potassium, which is lighter than water, ascends within the jar; and as soon as the paper becomes soaked, decomposes the water with great rapidity. This metal has a greater affinity for oxygen than hydrogen has. The potassium, K, decomposes the water, H_2O, by uniting with its oxygen, O, and letting part of its hydrogen, H, go free. The latter gas collects at the upper

colouring matter. The only essential character of an acid oxide is, that it neutralises a basic oxide, and of a basic oxide, that it neutralises an acid oxide, so as to form a salt.

shut end of the gas jar, whilst the oxygen combines with the potassium, forming the oxide of potassium, or potass, KHO. If the jar be filled at the beginning of the experiment with infusion of purple cabbage instead of pure water, the conversion of the potassium into potass will be rendered manifest by the liquid changing in colour from purple to green. This decomposition may be illustrated thus:

Before decomposition........................H_2O and K.
After decomposition..........................KHO and H.

The metal sodium may be employed instead of potassium.

269. Iron cannot decompose water at ordinary temperatures, such as 60° Fahrenheit; but if heated red-hot, it acts like potassium or sodium. This property of iron is generally illustrated by sending the steam of water, H_2O, through an iron tube like a gun-barrel, placed across a furnace, when the iron, Fe, unites with the oxygen, O, and the hydrogen, H, is set free; but so complicated and troublesome an apparatus is not necessary for the purpose. If a bar of iron be raised to a full red heat, it will be found to decompose water when plunged below its surface. To prove this, all that is needed is to thrust the red-hot bar below the mouth of a gas jar filled with water, when bells, apparently of air, will be seen to rise from the iron, and collect in the upper end of the jar. These bells consist of hydrogen gas mixed with a little air. The decomposition is similar to that in the case of potassium:

Before decomposition....................$4H_2O$ and 3Fe.
After decomposition.....................Fe_3O_4 and 8H.

Zinc also decomposes water at a red heat.

270. If sulphuric acid, H_2SO_4, or certain other acids be added to water, iron or zinc will decompose it without being raised to a red heat. This is the method generally followed. Zinc is preferred to iron on account of its greater purity, and is employed in small pieces or in a granulated state procured by pouring molten zinc into water. One ounce of zinc will

disengage 626 cubic inches, or two and a quarter, gallons of hydrogen from water. A retort (fig. 5) may be used, or a flask with a bent tube (fig. 6); but the most convenient piece of apparatus is a double-necked bottle, into the one neck of which a funnel passing through a cork is fixed, and into the other a bent tube (fig. 16). When this arrangement is made use of, zinc and water are introduced into the bottle by one of the necks, before the delivery or exit-tube is fixed in, and sulphuric acid (oil of vitriol) is then added by means of the funnel. The gas is collected at the pneumatic trough exactly in the same way as oxygen is; and special care must be taken not to begin filling the jars till the whole of the air is expelled from the generating vessel, as hydrogen forms an explosive mixture with atmospheric air.

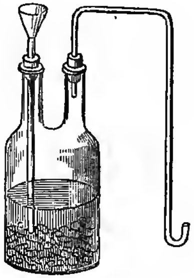


Fig. 16.

271. In the process just described, the zinc, Zn, combines with the oxygen, O, of the water H_2O, forming oxide of zinc, ZnO, liberating the hydrogen, H. The oxide thereafter unites with the sulphuric acid, SO_3, forming the sulphate of zinc, $ZnSO_4$. It may be expressed thus:

First stage..................$H_2O + Zn = ZnO$ and 2H.
Second stage................$ZnO + SO_3 = ZnSO_4$.

272. Iron filings or scrap-iron may be employed in place of the zinc, when the sulphate of iron is formed, and hydrogen is liberated. Zinc and hydrochloric acid will also yield hydrogen. Zinc, when heated with a solution of caustic potash in a retort or flask, likewise evolves hydrogen.

273. A cheap method of procuring hydrogen on the large scale is to transmit steam over coke or charcoal heated in a tube or retort to a low red heat. The carbon of the coke or charcoal takes the oxygen from the water, forming carbonic acid (anhydride), whilst the hydrogen of the water is set free. When the mixed gases are sent over quicklime, the carbonic acid

(anhydride) is retained by the lime, and the hydrogen is received comparatively pure. If the coke or charcoal be too highly heated, carbonic oxide is produced, which cannot be separated from the hydrogen by means of the lime.

274. *Properties.*—Hydrogen is the lightest body in nature, being fourteen and a half times lighter than air, and sixteen times lighter than oxygen. One hundred cubic inches weigh only 2·14 grains. Its lightness may be demonstrated by filling a bladder, or waterproof cloth bag, with hydrogen, and employing this by attaching it to a tobacco-pipe, to blow soap-bubbles with the gas. These ascend with great rapidity. A better method is to fill a small balloon made of gold-beater's skin or collodion with hydrogen, which can easily be done by attaching it to the neck of a bottle containing zinc and diluted sulphuric acid till it is filled with gas (fig. 17). When the balloon is small, the vertical tube should be some inches in length, and filled loosely with fragments of quicklime, which retains the sulphuric acid spirted up, and prevents it corroding the balloon, as well as arrests the moisture which accompanies the gas, and may render it so heavy that it cannot raise the balloon. The lightness of hydrogen may also be observed by filling two jars with hydrogen, and uncovering one with its mouth upwards and the second with its mouth downwards. In a minute or less the hydrogen will have escaped from the first, but will be found abundantly in the second on the application of a light.

Fig. 17.

275. Sounds produced in hydrogen are very feeble. The best way of illustrating this is to ring a bell within a large jar standing on the air-pump plate and filled with hydrogen. After the ear has become accustomed to the sound, the hydrogen is allowed to escape, and air admitted in its place. The sound now is much louder. This method, however, requires a somewhat costly and complicated

arrangement. A simpler plan is to sound an organ-pipe, flageolet, or whistle, first with air and then with hydrogen, which may be sent through the musical instrument from an air-tight bag or gas-holder. Another very simple method is to fill a bottle with hydrogen, and then to close it by a cork, to the lower end of which a piece of metal or glass is attached by a piece of string, so as to admit of its striking against the sides of the bottle like the clapper of a bell. The experiment is to be made with the bottle alternately filled with air and with hydrogen; but the difference will not be observed unless the glass vessel be of considerable dimensions, and its walls tolerably thin.

276. Hydrogen has a very high refracting power for light. It does not support respiration or the life of animals; but when pure, it is not poisonous; the death of an animal when introduced into an atmosphere of pure hydrogen being due to the deprivation of oxygen which is required during respiration. Occasionally, the hydrogen contains arseniuretted hydrogen, due to the zinc or the sulphuric acid used in its preparation containing arsenic, and then the hydrogen is highly poisonous.

277. Hydrogen has never been liquefied nor solidified, and it is soluble in water only to the extent of 2 cubic inches of the gas in 100 cubic inches of water. It is combustible in air, but does not itself support combustion. Both these properties may be seen at once by introducing a lighted candle into a jar of hydrogen, held with its mouth downwards. The hydrogen burns at the mouth of the jar, where there is air to support its combustion; whilst the candle, if thrust up so as to be enveloped by the gas, is extinguished. If a jar of hydrogen be held with the mouth upwards, and a light applied, the gas burns with great rapidity, its lightness enabling it to ascend swiftly.

278. The light evolved by burning hydrogen is pale yellow, and has very little illuminating power. It gives out, however, an intense heat. When it burns in air or in oxygen, it forms water by combining with eight times its weight of the latter gas, as we have frequently mentioned. The production of

water in this way is best illustrated by using the arrangement already described for filling a balloon, where the gas is dried by passing through quick-lime, and may be kindled at the upper extremity of the drying tube. If a white saucer, or dry glass vessel, be held over the burning jet of gas (fig. 18), it becomes rapidly covered by drops of water; and it is easy, by maintaining the combustion within a two-necked globe, which allows a current of air to pass through it, and can be kept cool, to collect the water produced. For every two grains, or one hundred cubic inches, of hydrogen burned, eighteen grains of water will be obtained. Fig. 19 represents a glass jet of the proper shape. It may be of any length, and only requires to be passed through a perforated cork fitting the neck of the bottle from which hydrogen is issuing.

Fig. 18.

279. If hydrogen, instead of being burned at a jet, or at the mouth of a jar, be mingled with air, or oxygen, before a light is applied, the combustion of the entire volume of inflammable gas is instantaneous (or nearly so), and is attended by a loud explosion. We have already seen that the combining measure of hydrogen is the same as that of oxygen. When, therefore, we wish to explode the gases together, we take two volumes of hydrogen and one volume of oxygen, so that we fill a vessel two-thirds full of hydrogen, and one-third full of oxygen. If we employ air, one-fifth of which only is oxygen, we must take five volumes to two of hydrogen, or two and a half of air to one of the combustible gas.

280. Wide-mouthed vessels much thicker and stronger than the ordinary gas jars must be used in these experiments; and it is well to wrap the vessel in a towel before applying a light, so that, if the glass should break, the hands may escape injury. The fact that hydrogen forms an explosive mixture with air, should be

Fig. 19.

kept in recollection whenever experiments are made with the gas, as many accidents have occurred from ignorance or forgetfulness of this fact.

281. The sound in such explosions is occasioned by the concussion of the air, from the propulsion against it of the steam resulting from the combination of hydrogen and oxygen, which is in a highly-expanded state, owing to the heat produced.

282. If the detonations are made to succeed each other very rapidly, a musical note is produced. To observe this, a jet of hydrogen should be kindled, and a glass tube, open at each end, about two feet long, placed over it like a chimney (fig. 20). The flame elongates, and begins to flicker, an effect which is owing to the tube preventing a large volume of air reaching the jet. The gas, in consequence, has to mix *comparatively* slowly with a volume of air sufficient to burn it, and combustion then happens with a slight detonation. This process of mixture with air, followed by explosion, proceeds with great rapidity, so that the detonations succeed each other with such swiftness as to prevent the ear observing the intervals between them. A continuous sound, or musical note, is thus produced, which varies according to the size of the jet, and the length and diameter of the glass chimney placed over it. This arrangement has been called the hydrogen harmonicon; but any of the combustible gases will produce musical notes if burned in the same way.

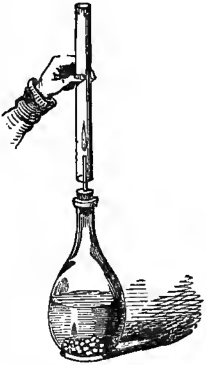


Fig. 20.

283. Hydrogen and oxygen may be preserved mixed for any length of time without combining. Combination is determined in a moment by the introduction of any body at a red heat, by the application of flame, or the passage of an electric spark. Another very interesting method of determining the union of

the gases, is the introduction into a mixture of them of a piece of the metal platinum perfectly clean, and especially of spongy platinum, which, in a way not easily explained, causes their rapid union, with the evolution of heat and light.

284. An instantaneous lamp has been devised, which takes advantage of this property of platinum. It consists essentially of a vessel in which hydrogen is generated and stored (fig. 21), with a stop-cock *a*, by means of which a jet of the gas can be directed against some finely-powdered, or, as it is called, spongy, platinum, contained in a small brass cup *b*. The hydrogen mingles with air before reaching the platinum, which at once inflames the mixture, and a match may be lighted at the flame. This ingenious apparatus is now superseded by the lucifer-match.

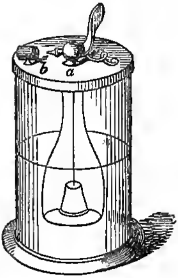


Fig. 21.

285. It has already been mentioned that the flame of hydrogen is very feebly luminous. The highest illuminating power, however, may be conferred upon it by introducing into its flame any infusible solid, which it may raise in temperature. The solid made use of for this purpose is generally quick-lime, and the hydrogen is maintained in full combustion by mixing it with oxygen before kindling it. This is most easily and safely effected by conducting hydrogen through one tube, and oxygen through another, from separate gas-holders containing them. These tubes terminate in a single canal, where they are allowed to mix, and from which they are conducted by a curved jet or nozzle, which permits the mixed gases to flow out against a piece of lime. The wood-cut (fig. 22) represents a suitable arrangement.

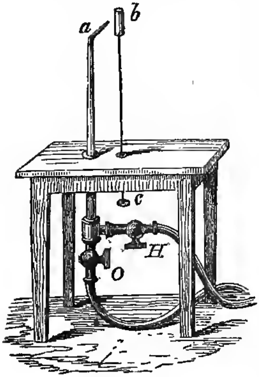


Fig. 22.

H and O are the tubes conveying hydrogen and oxygen from gas-holders or bags containing these gases; *a*, a curved tube terminating in a small aperture, by means of which the burning gases are directed against the lime; *c*, spindle to support lime; *b*, cylinder of quick-lime or limestone.

286. In using this arrangement, the hydrogen is first kindled, and allowed to heat the lime, which communicates to its flame a brick-red colour, owing to the combustion of the metal calcium, of which lime is the oxide. The oxygen is then turned on, when the flame becomes much smaller, and changes to a bright white light of the greatest intensity. It is the lime in reality, however, which evolves the light, the office of the burning gases being to maintain the solid at the high temperature essential to its exhibition of luminosity. This lime-ball light, as it is called, rivals sunlight in purity and brilliancy. It is visible on a clear night at a distance of nearly a hundred miles.

287. The intense heat evolved during the combustion of hydrogen in oxygen is turned to account in a modification of the arrangement just described, which is distinguished as the oxyhydrogen blowpipe. In it the tubes conveying the hydrogen and oxygen terminate in a canal, shaped exactly like the letter Y (fig. 23). The oxygen tube joins the one limb, the hydrogen tube the other, and the gases mix in the stalk of the Y, which terminates in a fine aperture like an ordinary gas jet. The most infusible substances, such as pipeclay and rock-crystal, are melted or even dissipated in vapour if exposed to the flame of the mixed gases. Steel, iron, antimony, copper, bismuth, and all the ordinary metals, burn with great brilliancy, and are most of them dissipated as oxides before this blowpipe flame. The heat it evolves far exceeds in intensity or temperature that producible by our most powerful furnaces. It is employed in the arts to melt the refractory metal platinum.

Fig. 23.

288. Hydrogen and oxygen form three compounds; namely, water, which is the suboxide, H_2O [or by the old notation,

the protoxide, HO]; *oxygenated water*, or the deutoxide, H_2O_2 [or binoxide, HO_2]; and the tritoxide, H_2O_3 [or teroxide, HO_3]. The second and third oxides of hydrogen are rare substances, possessing powerful bleaching and oxidising properties.

289. Water, H_2O [or by the old notation, HO], occurs tolerably pure in rain or snow collected in the open country, at a distance from dwellings. Spring, river, well, lake, mineral, and sea water, all contain various substances dissolved in them, which render them unsuitable for many purposes. It would be premature in this place to discuss the nature or properties of the substances which confer on ordinary water such characters as 'hardness,' 'softness,' medicinal virtues, and the like. These will be considered with more advantage under such bodies as sulphate and carbonate of calcium, carbonic acid, hydrosulphuric acid, &c., which impregnate many natural waters, and give them peculiar properties.

290. Water is obtained pure for chemical purposes by distilling it in a copper still provided with a condenser. Instead of a still, a glass retort may be used (fig. 24), the neck of which passes into a receiver, which is kept cool by placing it in a basin of cold water, or by surrounding it with cloth or bibulous paper kept wet by a stream of water. Pure water is composed of two parts of hydrogen united with sixteen parts of oxygen by weight.

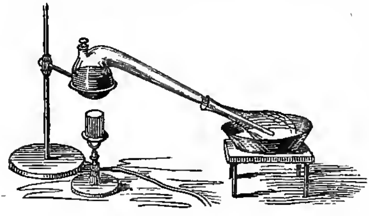


Fig. 24.

291. Another form of apparatus for the distillation of pure water on the small scale, is the Liebig's condenser (fig. 25), which consists of a flask or retort, A, into which the impure water is placed, and is heated. The steam rises, and passes through the tube, BB, which is surrounded by an outer tube, CC, between which and the inner tube a stream of cold water

is allowed to pass from a reservoir above. The steam is thus

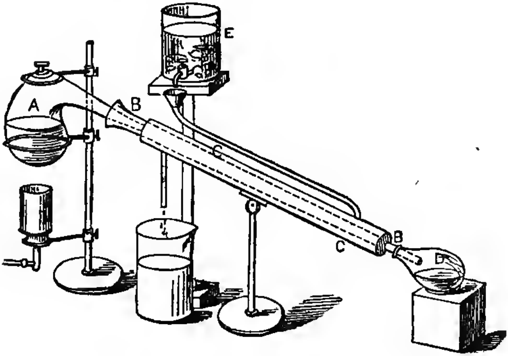


Fig. 25.

condensed, and passes into the receiver, D, as pure or distilled water.

NITROGEN.

Synonym, Azote; combining weight, 14; *symbol,* N; *density,* 0·972.
combining measure, one volume or □

292. *Distribution.*—Nitrogen constitutes four-fifths, or 79 per cent., of air by volume. It is present in the native nitrates or nitres, saltpetre (nitrate of potassium), and cubical nitre (nitrate of sodium). It occurs also in coal, and in a few other minerals, and is a constant ingredient of plants and animals.

293. *Name.*—The term nitrogen signifies the nitre-producer, and was given to this substance in relation to its occurrence in the important substance saltpetre. Azote is derived from α, signifying, in combination, to deprive of, and ζωη (zoë), life, and was applied to this substance by the French chemists in consequence of animals dying when introduced into the gas. It is not, however, poisonous, as the name might imply, but destroys life, as water does when an animal is drowned in it, by excluding air, and so occasioning suffocation.

294. *Preparation.*—Nitrogen may be prepared in two ways. The one, which consists in heating nitric acid on raw butcher-meat in a retort, does not readily yield it pure. The other, and more convenient method, consists in depriving atmospheric air of the oxygen, which forms a fifth part of its volume, and thereby leaving its nitrogen free.

295. For this purpose, some combustible, such as hydrogen, sulphur, alcohol, or phosphorus, is allowed to burn in a confined portion of air till it goes out. The combustible must be one whose oxide is soluble in water; thus hydrogen forms water; alcohol, water and carbonic acid; sulphur, sulphurous acid; and phosphorus, phosphoric acid—all of which dissolve in water. The most convenient combustibles are alcohol and phosphorus. One or other of these is to be placed within a metallic cup, mounted on a pedestal, placed on the shelf or stool of the pneumatic trough, or in a basin of water (fig. 26). The combustible is then to be kindled, and a jar full of air placed over it.


Fig. 26.

296. If alcohol, C_2H_6O, be used, the carbon, C, and hydrogen, H, which it contains, unite with the oxygen, O, of the confined air, and form carbonic acid, CO_2, and water, H_2O, which are dissolved by the liquid in which the jar stands. As soon as the alcohol ceases to burn, the water begins to rise within the jar, and ascends till it occupies about one-fifth part of its capacity, replacing the oxygen, which has been converted into water and carbonic acid. The gas which remains is the nitrogen of the air. Alcohol frequently ceases to burn before the whole of the oxygen is withdrawn from the air. Phosphorus, P, accordingly, which removes every trace of oxygen, O, is preferred; but when it is made use of, the nitrogen must be allowed to stand over water till the white fumes of anhydrous phosphoric acid, or phosphoric anhydride, P_2O_5, have been absorbed by the water.

297. Phosphorus will likewise slowly absorb the oxygen

from the atmosphere in the cold, and in a day or two a stick of phosphorus inserted in a jar of air placed with its mouth in a basin of water, will have taken up all the oxygen, and have left the nitrogen. The oxygen of the atmospheric acid will likewise be absorbed by moistened iron or lead filings or shavings, or the sulphides of the metals in a moist state.

298. Nitrogen may also be prepared by transmitting a stream of chlorine gas, Cl, through ammonia, $2(NH_4)O$, and by passing a current of atmospheric air through a tube containing red-hot copper turnings, when the copper, Cu, combines with the oxygen, O, to form black oxide of copper, CuO, and allows the nitrogen to escape.

299. *Properties.*—Nitrogen is characterised by the absence of all positive properties. It has no taste, colour, or odour; no action upon colouring matter; it neither burns nor supports combustion; and it cannot maintain animal respiration. It has never been liquefied nor solidified even when subjected to the greatest pressure and the most intense cold. It dissolves in water to the extent of 2 cubic inches of nitrogen in 100 of water at 32° F., and 1½ cubic inches at 60° F. 100 cubic inches of nitrogen at 60° F. and 30 inches bar. weigh 30·119 grains.

300. In relation to combustion, gases are divisible into three classes: 1. Those which support combustion, of which oxygen is the best example; 2. Those which are combustible, of which hydrogen is one; and 3. Those which neither burn nor support combustion, among which nitrogen ranks. A candle introduced into a jar of the gas (fig. 27) is at once extinguished without kindling the nitrogen.

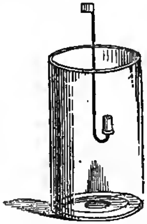


Fig. 27.

301. In reality, however, nitrogen is combustible. This may be proved by mingling it with hydrogen, and kindling the mixture as it issues from a jet into the air. The nitrogen burns to a small extent along with the hydrogen, so that whilst the latter combines with oxygen to form water, the former unites with the same gas

to form nitric acid. Electric sparks or lightning discharges, when they pass through air, determine in like manner the combustion of the nitrogen, and the production of nitric acid.

302. Negative as seem all the properties of nitrogen when uncombined, no substance forms compounds possessed of more marked properties, as nitric acid, HNO_3; ammonia, $2(NH_4)O$, and the alkaloids strychnine, morphine, &c., may serve in the meanwhile to illustrate. Before discussing, however, any of the compounds of nitrogen, it is desirable to consider the constitution of atmospheric air, of which it forms so large a portion.

THE ATMOSPHERE.

303. The air is not a chemical compound, but a mechanical mixture of several gases. The most abundant of these is nitrogen. The next in quantity is oxygen, on which the positive chemical characters of the air, such as its power to support combustion and animal respiration chiefly depend. Besides these gases, carbonic acid, CO_2, aqueous vapour, H_2O, ammonia, $2(NH_4)O$, nitric acid, HNO_3, and ozone are present in small quantities, as well as traces of light carburetted hydrogen, CH_4, and in towns, of hydrosulphuric acid (sulphuretted hydrogen), H_2S, and sulphurous acid, SO_2. Minute quantities also of the different volatile compounds which are evolved at the earth's surface, find their way into the atmosphere, but do not permanently affect its constitution.

304. The principal gases are constantly present, and are essential to the maintenance of animal and vegetable life on the surface of the globe. They occur in the following proportions in the atmosphere: In 100 volumes of air there are present 79 volumes of nitrogen and 21 of oxygen. Air varies slightly in composition, but the average proportion of oxygen found in it is a little less than 21, being 20·81, and the nitrogen a little more than 79, being 79·19, volumes per cent. Thus it may contain 20·9 oxygen, and 79·1 nitrogen. It may, however,

with sufficient propriety be regarded as always presenting the composition stated above; and it will be found convenient to call the proportion of oxygen one-fifth, and that of nitrogen four-fifths, of the volume of air.

305. In 100 parts by weight of air there are 76·99 or 77 by weight of nitrogen and 23·01 or 23 of oxygen. The one of these latter numbers is not a multiple of 14, the atomic weight of nitrogen, nor the other of 16, the atomic weight of oxygen, as they should be, if air were a chemical compound.

306. Of carbonic acid there are present from 4 to 6 measures in 10,000 of air; and the proportion of ozone is various, being greater in country districts than in towns. The amount of aqueous vapour is dependent chiefly upon temperature, so that it varies with latitude, the season, region of the atmosphere, &c. The quantity of ammonia and nitric acid is small, and their presence can only be shewn by the evaporation of rain water. The ammonia occurs in the atmosphere, combined with carbonic acid, as carbonate of ammonium; and the nitric acid, as nitrate of ammonium.

307. The presence of oxygen in the atmosphere is proved by combustible bodies becoming converted into oxides when made to burn in it. Thus, hydrogen becomes water, the oxide of that gas. The presence of nitrogen is demonstrated by the result of combustion in confined portions of air, as we have mentioned whilst describing the method of obtaining free nitrogen.

308. The relative quantity of these gases may be most simply ascertained by introducing air into a tube, graduated into a hundred equal parts (fig. 28). A piece of phosphorus attached to a wire is then to be passed up into the confined portion of air, the tube all the while being kept vertically in the pneumatic trough with its mouth downwards, and under water. The arrangement is to be left undisturbed for twelve hours, during which period the phosphorus, P, though not kindled, slowly combines with the oxygen, O, of the air,

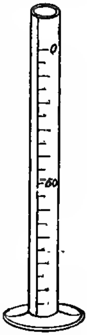


Fig. 28.

forming anhydrous phosphoric acid, P_2O_5, which the water dissolves. At the end of the time specified, the phosphorus may be withdrawn, and the volume of gas which remains observed. The water should rise through 21 spaces, replacing the oxygen withdrawn, and leave 79 volumes of nitrogen. A solution of pyrogallic acid and potash may be used instead of the phosphorus, and will act more quickly.

309. The presence of carbonic acid, CO_2, in the atmosphere is demonstrated by leaving a vessel containing lime-water, CaO, in the open air. The lime-water becomes turbid, owing to the combination of the carbonic acid with the lime to form the insoluble carbonate of calcium (chalk), $CaCO_3$. A more sensitive reagent for exhibiting the presence of carbonic acid in air is to expose some clear baryta water in an open vessel, when the carbonic acid unites with the baryta, BaO, and forms carbonate of barium, $BaCO_3$.

310. Ozone is regarded as an allotropic modification of oxygen, and is present in the atmosphere to a minute extent, and may be recognised to be there by exposing slips of paper moistened with iodide of potassium and starch, when the paper passes from white to a more or less deep purplish blue, according to the amount of ozone and the length of time of the exposure. The quantity of ozone in country districts is greater than that in towns, and, indeed, in crowded thoroughfares ozone ceases to be recognisable. It has a great power of destroying offensive odours, and is naturally serviceable in oxidising infectious and other deleterious matters which are evolved where animals are congregated. It is also a powerful bleacher, and is regarded as the agent in the air which whitens clothes when these are sun-bleached. Antozone is another modification of oxygen.

311. The uses of the several gases and vapours mentioned, are now pretty well ascertained. The importance of water-vapour to animal and vegetable life does not call for lengthened illustration. The oxygen supports the respiration of animals, entering their bodies by their lungs or other breathing organs, and effecting changes on the fluids and tissues, essential to the

maintenance of life. Oxygen also enters plants, dissolved in the water which they absorb by their roots.

312. The nitrogen of the atmosphere serves to dilute the oxygen to the point, or strength most suitable for the wants of living beings. Animals made to breathe pure or undiluted oxygen are thrown into a state of fever, which quickly proves fatal. Nitrogen, however, also serves an important purpose in the economy of nature, by increasing the volume of the atmosphere without conferring upon it active chemical properties. Provision is thus made for the occurrence of winds, the tempering of climate, the diffusion of heat, the scattering of the sun's light, and the realisation of other useful ends essential to the welfare of man and the other living inhabitants of the globe.

313. The carbonic acid supplies plants with their most abundant element, which they obtain from it by decomposing it into its constituents, carbon and oxygen; the former they retain, the latter they restore to the atmosphere. This decomposition is effected chiefly by the leaves, but also by the other green parts of plants. It occurs only during the day; and to the greatest extent when the sun is shining most brightly. During darkness, plants totally lose the power of decomposing carbonic acid. This remarkable action of living vegetables will be referred to again under the head of carbonic acid.

314. The ammonia which is constantly reaching the air, as a product of the decomposition of animal and vegetable matters, is brought down to the earth, as we have seen, by each shower that falls; and entering the roots of plants along with the rain-water, supplies them with nitrogen, an element essential to their growth. The nitric acid performs a similar service to plant life.

315. The physical properties of the atmosphere are of as much interest as the chemical, but cannot be discussed at length here. 100 cubic inches of air, free from moisture, and taken at 60° F. and 30 inches bar. weigh 31·074, which is a little more than 31 grains, so that a cubic foot of air will weigh 536·96, or nearly 537 grains. The relative solubility of the various gases of

the atmosphere in water is of the utmost importance in relation to the life of fish and other animals inhabiting the sea and our rivers. The oxygen is dissolved to the extent of two parts for every one part of the nitrogen, and hence the proportion of oxygen to the nitrogen in the gases in solution in natural waters is eight times greater than the proportion in the atmosphere itself.

316. The height of the atmosphere is about forty-five miles—that is to say, it spreads from the earth in every direction to that extent, so that our globe may be compared to a cannon-ball enclosed in a sphere of glass. The density of the atmosphere, however, is not the same throughout, but rapidly diminishes as we recede from the earth, its lower strata being compressed by those above them, so as to contain within the same volume a much greater weight of air. Were the atmosphere of uniform density throughout, and its density the same as it is at the surface of the sea, its height above the earth would be only five, instead of forty-five miles, as it actually is.

317. The density of air is estimated at 1·000, and it is the standard of comparison for the specific gravities of gases and vapours. It is 810 times lighter than water, and 11,000 times lighter than mercury. Nevertheless its quantity is so considerable, that it exerts a great pressure on objects at the surface of the earth. This pressure, at the level of the sea, is equal in amount to fifteen pounds on each square inch, or to the weight of a column of mercury thirty inches in height, or one of water nearly thirty-four feet. This pressure is constantly varying, however, even at the same level, as the risings and fallings of the barometer enable us to mark and to measure.

318. The air, as we have particularly mentioned, is a mechanical mixture, not a chemical compound; nevertheless it is exceedingly uniform in constitution. No essential difference has been detected in the composition of air in one part of the world as compared with another; nor does air brought from the summits of high mountains, or the greatest elevations accessible to balloons, appreciably differ from that in the

lowest valley or the deepest mine. The atmosphere, moreover, of unhealthy districts, such as the Campagna of Rome, is similar in chemical constitution with that from the most salubrious localities, from the top of Mont Blanc, or from above the sea. These remarks apply chiefly to the nitrogen, oxygen, and carbonic acid of the air; and they lead to the discussion of a very important law, which regulates the mixture of gases with each other.

DIFFUSION OF GASES.

319. If the gases of the atmosphere were combined chemically, its uniformity in composition would not surprise us; neither would this be remarkable if the gases had the same densities; but we have already seen that their specific gravities are very different. The following numbers illustrate this:

Gas.	Specific Gravity.
Air	1·000
Nitrogen	0·972
Oxygen	1·1056
Carbonic Acid	1·529

Where the densities are so different, we should expect that the gases would arrange themselves in the order of their densities; so that the lightest of the three, the nitrogen, should accumulate in the upper regions of the atmosphere; and the heaviest of them, the carbonic acid, be found preponderating at the surface of the earth; whilst the intermediate oxygen occupied the middle space between the nitrogen and carbonic acid. Liquids which do not act chemically on each other invariably arrange themselves in layers according to their densities: thus oil, water, and mercury, even if shaken together, would speedily dispose themselves in strata, with the oil highest, and the mercury at the bottom. No such separation of the atmospheric gases takes place. A long shut tube full of air, kept for many months in a vertical position, is found to contain the gases mixed in the same proportion throughout its whole length.

320. What is still more curious, gases differing much more in relative density than those of the atmosphere, will uniformly mix with each other, although the heaviest be placed lowest. In illustration of this, the following instructive experiment may be tried: Fill one bottle at the pneumatic trough with carbonic acid, and another with hydrogen, closing their mouths afterwards with corks or stoppers. Place the carbonic acid bottle standing on a table, and fix into its mouth, by means of a perforated cork, a glass tube two or three inches long, having attached to its upper extremity a second cork, fitting the mouth of the hydrogen bottle, into which it is to be inserted, the hydrogen bottle having its mouth turned downwards. The bottles thus arranged, as in the accompanying figure (fig. 29), are to be left undisturbed for an hour or more. Carbonic acid is twenty-two times heavier than hydrogen, yet it ascends through it, the greatly lighter hydrogen simultaneously descending through the heavier gas, till ultimately an exactly uniform mixture of the gases is contained in the bottles, and this notwithstanding the narrowness of the tube which connected them.


Fig. 29.

321. The presence of carbonic acid in the upper bottle (originally filled only with hydrogen) may be shewn by pouring into it lime-water, which will, on agitation, become milk-white, owing to the production of carbonate of calcium. The presence of hydrogen, in like manner, in the lower bottle (at the beginning of the experiment occupied solely by carbonic acid), may be demonstrated by transferring its contents at the pneumatic trough to a gas jar, and adding a little air or oxygen. The hydrogen will then burn on applying a flame. If oxygen be not added, the carbonic acid prevents the combustion of the hydrogen. This simple experiment shews that gases are under the influence of a force powerful enough to resist the influence of gravitation, and to prevent its taking effect upon mixtures of gases as it does on mixtures of liquids. It has been named *the force of gaseous diffusion;* and the spreading of gases through

each other, against the solicitation of gravity, is spoken of as their mutual *diffusion.*

322. It is this diffusive force which maintains the atmosphere uniform in constitution; both by retaining in a state of mixture gases which have once mingled, and by causing the uniform diffusion through the atmosphere of every gas and vapour which reaches it, whether it be light or heavy. Thus when hydrogen is allowed to escape from a balloon, it does not ascend to the upper regions of the atmosphere, but diffuses equally through it in all directions. In like manner, the carbonic acid which the combustion of fuel on the earth is constantly throwing into the air, does not remain at the surface, or descend into pits and mines, but spreads quite uniformly through the whole mass of air. So also the oxygen, which, as we have seen, plants are constantly separating from carbonic acid during daylight, does not accumulate around them, but is uniformly mingled with the other constituents of the atmosphere. The air is thus maintained of equal purity throughout. A noxious gas like carbonic acid, which would prove injurious if confined to one spot, is thus rapidly diluted, and so rendered harmless; and a useful gas like oxygen is speedily diffused through the whole atmosphere, so that every living creature equally profits by it.

323. When gases exchange places with each other, in virtue of the force of diffusion, they do not, whilst diffusing, replace each other in equal volumes; but, on the other hand, a larger volume of a light gas passes in one direction, than of a heavy gas in the opposite. This admits of being illustrated by a simple and very beautiful experiment. A glass tube or cylinder, open at both ends, from one to two feet in length, and from half an inch to two inches in diameter, is closed at one extremity by a plug or plate of stucco, about half an inch in thickness, and well dried. Stucco, when dry, is traversed by a multitude of very fine pores or canals, through which gases pass readily. At the same time it affords a certain amount of obstruction to their passage, which enables the law regulating their diffusion through each other, when of different densities, to be observed.

324. Such a cylinder as we have described is to be filled with hydrogen, but not at the water-pneumatic trough, as this would wet the stucco, which then becomes impervious to gases. The cylinder is most conveniently filled by holding it over a vertical tube proceeding from a gas-holder, a large jar, or bag full of hydrogen. The tube from which the hydrogen is issuing, is passed up till it almost touches the stucco plate, over which a square of window or plate glass is laid whilst the gas, which is supplied in a rapid stream, is displacing the air. When the cylinder is full of hydrogen, the tube is quickly withdrawn, and the mouth of the cylinder closed by a gas-tray. This is retained in its place by one hand, whilst a finger of the other is laid on the glass plate covering the stucco, till the cylinder has been transferred, with its open end downwards, to a basin of water (fig. 30). The tray and glass plate are now removed, and the eye fixed on the surface of the liquid within the cylinder.

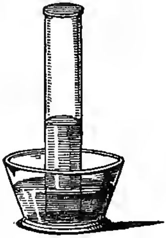


Fig. 30.

325. The plate of stucco is now in the condition of a porous screen or partition, on the upper side of which there is one (complex) gas—namely, air, and on its lower side another—namely, hydrogen, which is more than fourteen times lighter. The gases immediately begin to exchange places through the stucco; but, in virtue of the law we have mentioned, a much larger volume of the lighter hydrogen ascends in the one direction, than of the heavier air descends in the other. Thus whilst nearly four cubic inches (3·83) of hydrogen leave the tube, only one cubic inch of air enters it. The water, accordingly, rapidly rises to fill the space previously occupied by the hydrogen, which has not been replaced by an equal volume of air. For every four cubic inches (or nearly so) which escape, the water rises three cubic inches, being forced upwards by the pressure of the air acting on the liquid in the basin.

326. If the cylinder, when filled with hydrogen, were covered by a large bell-jar full of oxygen, then exactly four cubic inches

of hydrogen would leave the tube for each cubic inch of oxygen that entered it. These numbers—namely, 4 in the case of hydrogen, and 1 in that of oxygen—are inversely as the square roots of the densities of these gases, for oxygen is exactly sixteen times heavier than hydrogen, or their relative densities are as 16 (O) to 1 (H), whilst the square root of 16 is 4, and that of 1 is 1. If the gases replaced each other in volumes, which were *as* the square roots of their densities, we should have four cubic inches of oxygen entering the stuccoed cylinder for one of hydrogen that left it; and the water, if originally standing at some height within the cylinder, would descend instead of ascending. Exactly the reverse of this we have seen to be the case. It is the hydrogen which gives four cubic inches, whilst the oxygen returns only one. Or the replacing volumes are not *as*, but *inversely as*, the square roots of their densities.

327. It is the same with other gases, so that it can be announced, as a general law, that the *diffusion-volumes* of gases —that is, the volumes in which they replace each other—are inversely as the square roots of the densities of the gases. If this particular law be forgotten, the more general one may be remembered, that when light and heavy gases are exchanging places, a larger volume of the light gas passes in the one direction than of the heavy gas in the other.

328. The spread of infectious diseases, the ventilation of apartments, the maintenance of animal respiration, and other important natural and artificial processes, are controlled by the law of gaseous diffusion, which belongs more strictly to that department of chemistry which borders on physics, and which may be more correctly designated Chemical Physics.

COMPOUNDS OF NITROGEN AND OXYGEN.

329. Nitrogen forms several important compounds both with oxygen and hydrogen. Those containing the latter element will be discussed along with the fixed alkalies. Three of the oxides

(of which altogether there are five, see par. 95)—namely, nitric acid, nitrous oxide, and nitric oxide—are important substances, and possess striking properties. The remaining two—nitrous and hyponitric acids—are less interesting bodies.

Nitric Acid or Nitric Anhydride.

Synonym, Azotic Acid; symbol, N_2O_5; *combining weight,* 108.
[*Old symbol,* NO_5; *combining weight,* 54.]

330. Nitric acid in a hydrated state (in combination with water) has been known from an early period, and still retains, as one of its titles, the appellation of aquafortis, given to it by the alchemists. It consists of two atoms (14 each = 28) of nitrogen, and five atoms of oxygen (16 each = 80), so that its atomic weight, when anhydrous, is 108 [or, by the old notation, it is composed of one atom of nitrogen and five atoms of oxygen (8), making 54]. It is scarcely known, however, except in a state of combination. What is ordinarily called free nitric acid is in reality a hydrate of that substance, consisting, when strongest, of one proportion of the nitric anhydride, N_2O_5, united to an atom of water, H_2O, forming two parts of hydrated nitric acid, HNO_3. Anhydrous nitric acid, or nitric anhydride, N_2O_5, may be procured in small quantity by passing a current of dry chlorine gas over dry nitrate of silver, $AgNO_3$, raised in temperature. The acid is obtained in transparent, colourless crystals, derived from the right rhombic prism, which fuse at 85°, and boil at 113°. The crystals are very unstable, and when enclosed in a tube, often give rise to violent explosions.

331. *Distribution.*—Nitric acid occurs in nature chiefly as the nitrate of potassium and nitrate of sodium. It is found also in the atmosphere in small quantity, especially after thunder-storms. It is believed to be produced as a result of the lightning-discharges (as it can be procured on the small scale by sending electric sparks through air), and to unite, after its formation, with the ammonia present in the atmosphere, so that it is found in rain-water as the nitrate of ammonium. Nitric acid is also

produced naturally by the slow oxidation of ammonia which is evolved from decomposing organic matter.

332. *Preparation.*—On the small scale, nitric acid is most conveniently prepared by distilling together in a glass retort, connected with a receiver (fig. 24), equal weights of oil of vitriol, H_2SO_4, and nitrate of potassium, $2KNO_3$. Nitrate of sodium, $2NaNO_3$, is employed instead of nitrate of potassium in the distillation of nitric acid on the commercial scale, as it is a cheaper salt, and moreover yields about 9 per cent. more nitric acid; and the apparatus used is a large iron retort lined with fire-clay (fig. 31, A), in which the nitrate of sodium and sulphuric acid are placed, and the escaping vapours of nitric acid are conveyed by a tube, C, into the receiver, B.

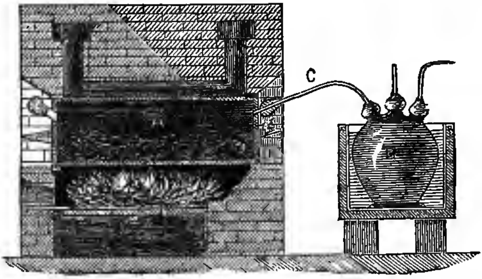


Fig. 31.

333. The sulphuric acid, SO_3, abandons the water to unite with the potass, K_2O, or soda, Na_2O, forming the sulphate of potassium, K_2SO_4, or the sulphate of sodium, Na_2SO_4; whilst the nitric acid, N_2O_5, unites in preference with the water, H_2O, forming the nitrate of water, or hydrated nitric acid, $2HNO_3$. The latter distils over into the receiver, where it condenses; whilst the sulphate of potassium, or the sulphate of sodium, remains behind in the retort. The decompositions may be illustrated thus in symbols:

Before decomposition—
$2KNO_3$ and H_2SO_4, or $2NaNO_3$ and H_2SO_4
[Old notation, KO,NO_5 and HO,SO_3, or NaO,NO_5, and HO,SO_3].

After decomposition—
$2HNO_3$ and K_2SO_4, or $2HNO_3$ and Na_2SO_4
[Old notation, HO,NO_5 and KO,SO_3, or HO,NO_5 and NaO,SO_3].

334. All nitrates yield nitric acid when distilled with oil of vitriol. The nitrate of soda, however, is the only one sufficiently abundant and cheap to be used on the large scale. A stronger acid than what is yielded by the above process, is prepared by taking the ordinary commercial nitric acid and adding its own volume of sulphuric acid (oil of vitriol), and having thoroughly mingled the whole together, redistil one-third of the entire mixture. The acid which comes over is known as fuming or gun cotton nitric acid.

335. *Properties.*—Nitric acid, HNO_3 [HO,NO_5], is a colourless, transparent liquid when quite pure, but generally exhibits a straw or yellow tint. Its density, when strongest, is about 1·520 at 60° F. (compared with water, 1·000), and it contains 85·72 per cent. of nitric anhydride, and 14·28 of water. It boils at 184° F. The ordinary commercial acid contains 60 per cent. of nitric anhydride and 40 of water, and has the symbol of $2HNO_3,3H_2O$, being 2 of the fuming acid united with 3 atoms of water. It has the specific gravity of 1·424, and boils at 250° F. It has a peculiar odour, a very sour taste, and is exceedingly corrosive. It dissolves nearly all the metals, except gold and platinum; combines with all the basic oxides and other bases, forming, by so doing, an extensive and important series of salts; and acts with the greatest energy on the majority of organic substances, converting them into new and generally remarkable compounds. It is of constant use in the laboratory, especially as a solvent of metals, and of ores and other minerals, and forms a very large class of compounds, which are called nitrates.

336. The following experiments will exhibit all its more striking properties:

1. Its effect on colouring matter may be observed by adding a few drops to infusion of litmus, or of the purple cabbage, either of which it will redden.

2. It stains the skin and other animal substances yellow, as

may be well seen by dipping white wool or worsted into the acid. In a concentrated form it rapidly destroys animal textures.

3. If iron, zinc, or copper, in filings or small fragments, be thrown into it, it evolves a dark brown or ruddy gas (hyponitric acid, N_2O_4).

4. When a solution containing nitric acid is treated with its own volume of sulphuric acid, and a solution of protosulphate of iron poured over the acid mixture, a dark layer of liquid is produced.

5. A grain or two of morphia (a crystalline substance prepared from opium), or any of its salts, if added to this acid, give it an orange-red colour, soon fading into yellow.

6. A weak solution of indigo in sulphuric acid has its blue colour destroyed by nitric acid, especially if the liquid be heated.

7. Paper soaked in a solution of potass, when dipped into nitric acid, and dried, becomes converted into match-paper, owing to the production of nitrate of potassium.

337. The word 'test' constantly occurs in chemical works, and its meaning may be explained here, on our first occasion of using it. A test is any substance which, when added to another, demonstrates the nature of that other by giving rise to some phenomenon which is presented by no body but one, so that if the peculiar phenomenon be witnessed, it implies the existence of the solitary body that can produce it. Thus, no liquid but nitric acid gives ruddy fumes when a metal is added to it; hence, the metals, such as copper and zinc, are tests of nitric acid, which they identify by causing the evolution from it of hyponitric acid.

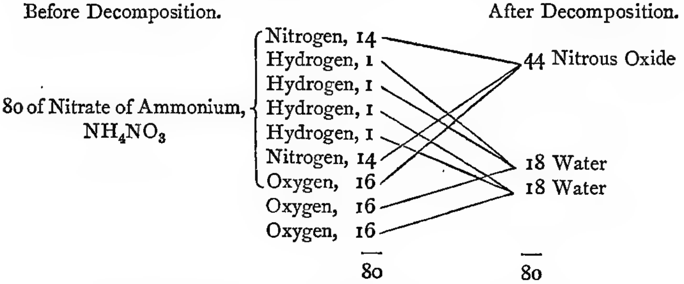
Nitrous Oxide.

Synonym, Suboxide [*Protoxide*] *of Nitrogen—Laughing-gas;*
combining weight, 44; *symbol,* N_2O; *density,* 1·527;
combining measure, 2 *or* □□
[*Old combining weight,* 22; *name, Protoxide of Nitrogen;*
symbol, NO.]

338. All the lower oxides of nitrogen are prepared, directly or indirectly, from nitric acid. To procure nitrous oxide, nitric

acid is neutralised with ammonia, and thereby is converted into the nitrate of ammonium, NH_4NO_3 [NH_4O,NO_5]. The nitrate of ammonium is placed in a retort (fig. 5), and heat applied, when it is entirely resolved into nitrous oxide, N_2O, and water, H_2O. The former may be collected in jars at the pneumatic trough whilst the water condenses. The change which occurs is the following: Nitrate of ammonium consists of two things—nitric acid and ammonia. Ammonia is a compound of nitrogen, hydrogen, and oxygen, $2(NH_4)O$; and nitric acid (anhydrous) is a compound of nitrogen and oxygen, N_2O_5. When heated, the atoms of hydrogen in the ammonia combine with the atoms of oxygen, part of which are derived from the nitric acid, and the remainder from the ammonia, forming water. The oxygen which is left combines with the two of nitrogen; the one of the latter derived from the nitric acid, the other from the ammonia; and in this way one atom of nitrous oxide is formed, which has the formula, N_2O.

339. As this process is an interesting and important one, we illustrate it by a detailed diagram:



Or in symbols................$NH_4NO_3 = N_2O$ and $2H_2O$
[or by the old notation......$NH_4O,NO_5 = 2NO$ and $4HO$].

340. *Properties.*—A colourless invisible gas, possessing a faint, agreeable odour, and pleasant, sweetish taste. It is soluble in about three-fourths of its volume of water, 100 measures of water, at 32° F., dissolving 130 measures of nitrous

oxide; at 59°, 77 cubic inches; and at 75°, 60 cubic inches. One hundred cubic inches of the gas weigh 47·29 grains.

341. It supports combustion brilliantly; throws into full flame a red-hot match or paper; and detonates when exploded with an equal measure of hydrogen. It is distinguished from oxygen by its solubility in water, its odour, and its taste, and principally by its producing no ruddy fumes when mixed with nitric oxide, such as oxygen does, and enabling sulphur introduced therein to burn with a beautiful rose tint.

342. Nitrous oxide passes into a colourless liquid under a pressure of 50 atmospheres at 45° F., and it can also be frozen. The liquid nitrous oxide has a specific gravity of 0·908, and boils at – 126° F., and becomes frozen into a transparent solid resembling ordinary ice at – 150° F.

343. The most interesting property of nitrous oxide is its action on the living body. When rapidly respired, it produces a transient, but very pleasant form of excitement, resembling that occasioned by wine or opium. The sensations and emotions experienced during the respiration of this gas are generally pleasurable, and are not followed by depression or other unpleasant symptoms. It frequently, however, occasions violent muscular action; the party breathing it, especially if restrained, struggling powerfully, and striking out in every direction. The gas, accordingly, should never be administered unless in the presence of one or two persons strong enough to resist effectually the struggles of the party under the influence of the nitrous oxide, otherwise he may injure himself and others.

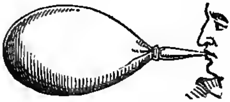


Fig. 32.

344. In the great majority of cases no unpleasant result follows the respiration of this gas; but on some persons it acts injuriously, and it cannot be considered safe to administer nitrous oxide in any circumstances, unless in the presence of a medical man. Care, moreover, should be taken that the gas is pure; in particular, that the nitric acid employed to prepare the nitrate of ammonium contains no

hydrochloric acid; and the salt should not be heated too strongly when collecting the nitrous oxide, otherwise the latter may be rendered irritating by the presence of fumes of nitrate of ammonium, and irrespirable products of its hasty decomposition.

345. Nitrous oxide is breathed from a waterproof cloth bag large enough to contain two or three quarts, having a wooden tube or nozzle (see fig. 32). It is replenished, as wanted, from a gas-holder.

Nitric Oxide.

Synonym, Deutoxide [Binoxide] of Nitrogen; symbol, NO; *combining weight,* 30; *density,* 1·039; *combining measure,* 2 *or* □□
[*Old symbol,* NO_2; *combining weight,* 30.]

346. *Preparation.*—By pouring diluted nitric acid on copper clippings or filings. A retort (fig. 5), or a double-necked gas bottle (fig. 12), may be employed in the preparation of this gas. It does not require the application of heat, and the gas is received in jars at the pneumatic trough (figs. 3 and 9). One ounce of copper acting upon four ounces of diluted acid yields 420 cubic inches of nitric oxide.

347. Nitric acid, HNO_3, contains three atoms of oxygen, nitric oxide only one for the atom of nitrogen, NO; if, therefore, we can remove a portion of the oxygen from the former, we shall convert it into the latter. The copper effects this separation of oxygen. Two atoms of nitric acid, HNO_3, are acted on by three atoms of copper, Cu, each of which unites with one of oxygen, forming the protoxide of copper, CuO, and giving rise to the separation of one atom of water, H_2O, and the liberation of two atoms of nitric oxide, NO, which escape with effervescence. The three atoms of oxide of copper then unite with six atoms of undecomposed nitric acid, forming three portions of the nitrate of copper, $Cu2NO_3$, and at the same time separating three atoms of water, H_2O. The change may be illustrated thus in symbols;

each of which, it will be remembered, represents an atom of the body taken:

Before decomposition..............$3Cu$ and $8HNO_3$
First stage of decomposition.....$3Cu$ and $2HNO_3 = 3CuO, H_2O$, and $2NO$
Second stage of decomposition..$3CuO$ and $6HNO_3 = 3Cu2NO_3$ and $3H_2O$

348. One-fourth only, it will be observed, of all the nitric acid taken is reduced to the state of nitric oxide, the remaining three-fourths being spent in uniting with the oxide of copper resulting from the decomposition of the one-fourth. The change may be illustrated more fully in symbols—the two portions of nitric acid which are decomposed being represented with each of their atoms separately, thus:

Before Decomposition.
$3Cu$ and $8HNO_3$.

First Stage.
$3Cu$ and $2HNO_3$.

$$\left.\begin{array}{ll} \mathrm{H} & \mathrm{H} \\ \mathrm{N} & \mathrm{N} \\ \mathrm{O} & \mathrm{O} \\ \mathrm{O} & \mathrm{O} \\ \mathrm{O} & \mathrm{O} \\ \mathrm{Cu} & \\ \mathrm{Cu} & \\ \mathrm{Cu} & \end{array}\right\} = \left\{\begin{array}{l} \mathrm{NO} \\ \mathrm{NO} \\ \mathrm{H_2O} \\ \mathrm{CuO} \\ \mathrm{CuO} \\ \mathrm{CuO} \end{array}\right.$$

Second Stage.
$3CuO$ and $6HNO_3$.

$$\left.\begin{array}{l} \mathrm{CuO} \\ \mathrm{CuO} \\ \mathrm{CuO} \\ \mathrm{2HNO_3} \\ \mathrm{2HNO_3} \\ \mathrm{2HNO_3} \end{array}\right\} = \left\{\begin{array}{l} \mathrm{H_2O} \\ \mathrm{H_2O} \\ \mathrm{H_2O} \\ \mathrm{Cu2NO_3} \\ \mathrm{Cu2NO_3} \\ \mathrm{Cu2NO_3} \end{array}\right.$$

349. The above is given as an example of the convenient way in which the symbols can be employed to illustrate chemical decompositions. The student should follow every chemical change in a similar way on his slate or in his note-book, and exercise himself in devising, instead of copying, diagrams. It will be found one of the most effectual methods of rapidly acquiring a knowledge of chemistry.

350. Symbols are much more expressive as used on a black board or slate than as they appear on a printed page, where they all stand at once before the reader, and the *stages* of a decomposition cannot be illustrated. In the present case, for

example, the student should first put down the H, N, O, O, O, representing one atom of nitric acid, and write down the second atom of acid in the same way. Beneath these, the three atoms of copper, Cu, Cu, Cu, may be placed, and thereafter these elements are to be associated together so as to form the two atoms of nitric oxide, one of water, and three of oxide of copper. Thereafter the second stage may be entered on, and the three atoms of oxide of copper being written down, followed by the three pairs of atoms of nitric acid, the subsequent changes due to the formation of nitrate of copper and water may be illustrated. Chalks of different colours may be used in the case of very young pupils, to make the diagrams more manifest; but, on the whole, one colour is preferable, as it can be copied by the pupil with the slate or lead pencil, or pen.

351. Nitric oxide may also be prepared by heating one ounce of nitrate of potassium, 8 ounces of protosulphate of iron, 7½ ounces of water, and 2½ ounces of sulphuric acid, when nitric oxide will be evolved to the extent of about 400 cubic inches.

352. *Properties.*—Nitric oxide is colourless and invisible, incombustible, irrespirable, and not a supporter of ordinary combustion; 100 cubic inches of the gas weigh 32·22 grains, and 100 volumes of water dissolve about 5 volumes of the gas. It possesses one remarkable and useful property: when it meets air, it gives rise to the production of a dark ruddy gas—hyponitric acid, N_2O_4. This change is owing to its combining with the oxygen of the air, $2NO + 2O = N_2O_4$; and, as may be expected, the action occurs still more markedly when oxygen instead of air mixes with nitric oxide.

353. The most striking way of exhibiting this property of the gas, is to fill a large jar with it at the pneumatic trough, and then suddenly turn its mouth upwards. If, whilst the ruddy fumes are in the jar, it be placed with its mouth downwards in a vessel of water, an additional phenomenon is observed: the water dissolves the hyponitric acid, and rapidly ascends within the jar.

354. To observe the effect with oxygen, a jar half full of

nitric oxide is placed upon the stool of the pneumatic trough, and oxygen gas rapidly added to it. This is effected by placing the mouth of the oxygen jar between the limbs or supports of the stool; the mouth of the jar being held downwards till it is completely within the funnel-shaped cavity of the stool. The shut end of the jar is then rapidly depressed, so that the gas it contains is quickly poured up through the funnel, as liquids are familiarly poured down through such an apparatus. (See fig. 33.) The trough-stool is omitted, for simplicity's sake, in the drawing. This experiment is a striking and beautiful one, from the instant development of the ruddy-coloured gas, and the rapid ascent of the water in the jar.

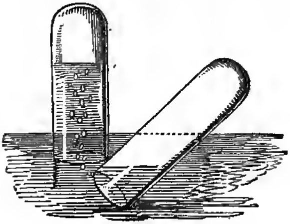


Fig. 33.

355. Nitric oxide thus supplies a delicate test of the presence of oxygen in any gaseous mixture. It is only necessary to add to the latter, whilst standing over water, a small volume of the gas in question. If oxygen be present, the gas will instantly become coloured. A dark-red tint will appear if there is much oxygen, a pale yellow if there is only a trace of it. A sheet of white paper held behind the glass vessel enables the eye to detect the slightest production of colour.

356. *Nitrous acid*, or *nitrous anhydride*, formerly known as *hyponitrous acid*, N_2O_3, combining weight 76 [old symbol NO_3, combining weight 38], is prepared by mixing 4 measures of nitric oxide with 1 measure of oxygen, both perfectly dry, and surrounding the vessel containing them by a freezing mixture. They condense into a volatile liquid. It may also be prepared by heating starch and nitric acid.

357. *Hyponitric acid*, N_2O_4, combining weight 92 [old symbol NO_4, combining weight 46], is prepared by mixing 2 measures of dry nitric oxide with 1 of dry oxygen; or, more conveniently, by heating nitrate of lead, $Pb2NO_3$; when the nitric acid

separates from the oxide of lead, and immediately resolves itself into oxygen and hyponitric acid, $Pb2NO_3 = PbO, N_2O_4$, and O. This acid forms the ruddy fumes which appear when nitric oxide meets air or oxygen. It can be condensed into a very volatile liquid, which is nearly colourless below zero, but yellow or brown-red at higher temperatures.

CARBON.

Combining weight, 12; *symbol*, C; *density as diamond*, 3·33 *to* 3·55. [*Old combining weight*, 6; *symbol*, C.]

358. *Distribution.*—Carbon occurs in nature uncombined, as the diamond, and as the mineral *graphite* or *plumbago*. It is much more abundant, however, in a state of combination. Thus, it occurs in union with oxygen in the carbonic acid present in the atmosphere, and which, in combination with lime and magnesia, forms, in the condition of limestone, so large a portion of the earth's crust. In union mainly with hydrogen, it is the chief constituent of coal; and along with oxygen, hydrogen, and nitrogen, it is an abundant ingredient of animals, and still more of plants.

359. The diamond is the purest form of carbon, and admits of being entirely converted into carbonic acid by combustion in oxygen. It is the hardest known substance; is a brilliant reflector of light, and is a non-conductor of heat and of electricity. It has not been fused even at the highest available temperatures, but when placed between the poles of the voltaic battery, the diamond swells up and becomes a black opaque substance resembling ordinary coke.

360. Graphite or plumbago has a specific gravity of 2·15 to 2·35, and is used in the manufacture of pencils. It goes ordinarily by the name of *blacklead*, but it contains no lead. Compounds of iron and clay are frequently present, but the purest specimens consist almost entirely of carbon. It occurs in veins, generally in granite and the primitive rocks, in various parts of the world, but only a limited portion of it is soft

enough to be used for pencils. The coarser varieties are employed as a coating for iron in burnishing fire-grates and fenders, and for making crucibles which will stand high temperatures. Graphite may be prepared artificially by dissolving charcoal in molten cast iron, and thereafter, on cooling, the latter parts with some of the carbon in the form of graphite.

361. Various important artificial varieties of carbon are made use of in the arts. They go generally by the name of charcoal. The four most important kinds are *wood charcoal, coke, animal charcoal*, and *lampblack.*

362. Wood charcoal is prepared by heating wood in iron retorts, or in covered mounds or *meilers.* The water originally present in the wood, its hydrogen, oxygen, nitrogen, and a large part of its carbon, are expelled in the form of various gases and vapours, and the excess of carbon left behind constitutes the wood charcoal of commerce. Charcoal may be made on the small scale by heating a piece of wood to a low red-heat in a glass tube. Wood charcoal is employed in the arts, and as a fuel. It is of much use in blowpipe experiments, and is largely consumed in the manufacture of gunpowder. A variety of wood charcoal called *charbon roux*, is prepared in France by passing air or steam at a temperature of 540° to 570° over and through the wood. The result is the production of a red charcoal, containing much hydrogen and oxygen, but very suitable as a fuel.

363. When coal is treated in closed retorts, as in the manufacture of coal-gas, or in brick ovens, the excess of carbon is left behind, forming a hard, shining, light solid, highly valued as an economical and powerful fuel. This substance, which is literally charred coal, and therefore best deserves the title of charcoal, goes nevertheless by the name of *coke,* the word charcoal, when not qualified by some prefix, being generally understood to signify the carbon of wood. Both wood charcoal and coke are good conductors of electricity, but are bad conductors of heat.

364. Animal charcoal is obtained by heating any animal

substance in retorts as long as volatile products are evolved. The variety of it best known as an article of commerce goes by the name of ivory-black, or bone-black, and is prepared by heating bones in covered vessels. It is not pure charcoal, but consists of one part of that substance mixed with nine parts of calcareous salts, chiefly combinations of lime with phosphoric and carbonic acids, which confer upon fresh bones their hardness and rigidity. These salts are left as a white earthy skeleton, when a bone is heated in an open fire so as to burn away its carbon. Animal charcoal, but especially bone-black, possesses in a remarkable degree a property not altogether wanting in wood charcoal—that, namely, of removing colour from liquids which owe their tint to the presence of animal or vegetable colouring matters. This bleaching power of bone-black leads to its great consumption by the sugar-refiner, who deprives brown sugar of its colour by filtering the solution of it through a stratum of coarsely-powdered charcoal. It acts still more powerfully if heated with the liquid to be bleached, and it is largely used in this way by the manufacturing and scientific chemist in the purification of organic substances; such, for example, as morphine or quinine.

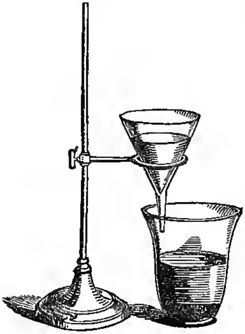


Fig. 34.

365. Animal, like wood charcoal, possesses the power of destroying odour as well as colour. The latter is employed, accordingly, to purify tainted water on shipboard, and occasionally to lessen the odour of game which has been overkept. When putrefying organic substances are covered with charcoal, they cease to be offensive to the sense of smell, owing to the power which the charcoal exerts in oxidising the gaseous effluvia. The decolorising power of animal charcoal may readily be demonstrated by boiling infusion of litmus, cabbage, or indigo, with

powdered ivory-black, and then passing the liquid through a paper filter. (See fig. 34.) The solution is rendered perfectly colourless.

366. Lampblack is the soot of imperfectly-burned combustibles. It is prepared by burning tar, the less marketable paraffin oils, or any other inflammable body containing carbon and hydrogen, with a limited supply of air. In such circumstances, the hydrogen of the combustible burns, but very little of the carbon is consumed. The greater part of it, on the other hand, is carried up in the state of a finely-divided powder in the current of warm air which rises from the burning body. When this warm current of gases impinges upon a cold surface, it deposits on it the carbon, which is allowed to accumulate, until it has formed a pretty thick layer, when it is scraped off, and forms the lampblack of commerce.

367. This variety of carbon, which is merely soot or condensed smoke, is very largely employed in the arts in the preparation of black pigments such as printer's ink. China-ink is a kind of lampblack made into cakes with gum-water. It does not possess the power of decolorising liquids or of absorbing odours, such as was observed in regard to animal charcoal and wood charcoal.

368. Carbon, in all its forms, is an exceedingly unalterable substance at ordinary temperatures, so that stakes of wood are charred at their surfaces before being driven into the earth, as a precaution against their decay. If carbon, however, be raised in temperature, it combines with oxygen, as we have seen in speaking of that gas, and by so doing, forms carbonic acid, CO_2, or carbonic oxide, CO, according to the proportion of oxygen supplied to it. Both of these oxides of carbon are compounds of great interest; we begin with carbonic acid:

Carbonic Acid.

Synonym, Carbonic Anhydride, Choke-damp; combining weight, 44; *symbol,* CO_2; *density,* 1·529; *combining volume,* 2 *or* ◻◻

[*Old combining weight,* 22; *symbol,* CO_2.]

369. *Distribution.*—Carbonic acid occurs, as we have already seen, in the atmosphere, and in large quantity in combination with lime and magnesia, in limestone, marble, shells, corals, &c. It is present in all natural waters; in some of them largely. It issues from the earth in various parts of the world, and is evolved in large quantity by volcanoes. It is a constant product, moreover, of animal respiration, and is given out by plants during darkness. Fermenting liquids, and most animal and vegetable substances whilst decaying, produce it, and the combustion of fuel at the earth's surface is an unceasing source of carbonic acid.

370. *Preparation.*—Carbonic acid is prepared in the laboratory in two ways. The one is a synthetic process, and consists in burning charcoal in oxygen; the other is an analytic one—namely, the displacement of carbonic acid from one of its compounds, such as the carbonate of calcium.

371. We have described, under oxygen, the arrangement required for burning charcoal in that gas (par. 257). When charcoal, C, is burned in oxygen, O, till the latter is converted into carbonic acid, CO_2, no change in volume occurs, so that a cubic foot, for example, of oxygen, after it is saturated with carbon, forms exactly a cubic foot of carbonic acid. Although the oxygen is not increased in volume by its conversion into carbonic acid, we need scarcely say that it is altered in weight, so that for every thirty-two parts of oxygen, we obtain, in virtue of its combination with twelve of carbon, forty-four of carbonic acid.

372. The production of carbonic acid during the combustion of charcoal is demonstrated by adding lime-water, CaO, to the jar originally full of oxygen in which the charcoal was

burned. The lime-water at once becomes milky, from the combination of the carbonic acid, CO_2, with the lime, CaO, and the consequent production of carbonate of calcium, $CaCO_3$.

373. The analytic process for carbonic acid is the one generally followed. Fragments of broken marble are placed in such a vessel as was used in the preparation of hydrogen or nitric oxide, and hydrochloric acid diluted with water is poured over the marble. Carbonic acid may be collected at the pneumatic trough, or by displacement of air—namely, by passing the gas to the lower part of a jar standing upright (fig. 35). Where carbonic acid is required in large quantity, as in charging soda-water, it is prepared from chalk and sulphuric acid.

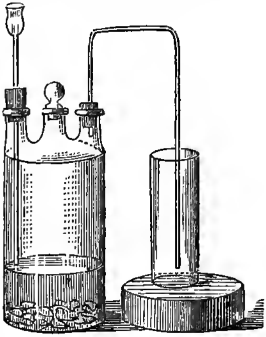
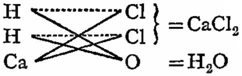


Fig. 35.

374. Any carbonate will yield carbonic acid if exposed to the action of the stronger acids, such as sulphuric, hydrochloric, nitric, or acetic.

375. The evolution of carbonic acid by the action of a stronger acid on a carbonate, admits of a simple explanation. Marble is the carbonate of lime, CaO,CO_2, or rather the carbonate of calcium, $CaCO_3$. Hydrochloric acid, HCl, however, has a much greater affinity for lime than carbonic acid has. The stronger acid, accordingly, unites with the lime, forming the chloride of calcium, $CaCl_2$, and water, H_2O, whilst the carbonic acid, CO_2, is set free in the gaseous form. The change may be expressed thus in symbols: $CaCO_3$ and 2HCl $= CaCl_2$, H_2O, and CO_2.

376. It will be observed that hydrochloric acid consists, as its symbol HCl implies, of hydrogen and chlorine, whilst lime, CaO, consists of the metal calcium and oxygen. When the acid and the base meet, they do not simply unite, but exchange constituents, and this double decomposition may be represented as follows in symbols:



In this, as in similar illustrative diagrams, the horizontal dotted lines shew the bodies in combination at the beginning of the decomposition; the oblique unbroken lines, the interchange which occurs during the decomposition; and the symbols placed after = the ultimate products. The full decomposition may be represented thus:

Before decomposition..................$CaCO_3$ and 2HCl.
After decomposition...................$CaCl_2$, H_2O, and CO_2.

377. *Properties.*—Carbonic acid, or carbonic anhydride, is a colourless, invisible gas, having a peculiar sharp, but not sour odour and taste. Water dissolves more than its own volume of this gas, and acquires, in consequence, a sparkling appearance, and refreshing, slightly-stimulant taste, such as all are familiar with in soda-water and other effervescing liquors. The briskness of many natural spring waters is due in considerable part to the amount of carbonic acid in solution. Under a pressure of 38½ atmospheres, at a temperature of 32° F., carbonic acid gas condenses into a clear and colourless liquid, like ordinary water, and may also be frozen into transparent ice, and be obtained as a snow-white solid.

378. Carbonic acid gas has the specific gravity of 1·529, being half again as heavy as air. One hundred cubic inches weigh, at 60° F. and 30 in. bar., 47·303 grains. It is uninflammable, extinguishes combustion, and cannot support animal respiration. It is distinguished from the other irrespirable and incombustible gases by the precipitate, already frequently referred to, which it produces in lime-water.

379. Its properties may be demonstrated by the following experiments: (1.) The odour of carbonic acid is best observed by holding the nostrils over soda-water, or a dissolved seidlitz powder, from which the gas is effervescing. (2.) Its taste is best

noticed by taking a draught of pure water which has been saturated with it. (3.) Such a solution is most easily prepared by half filling a bottle of water at the pneumatic trough with the gas, corking it, and shaking it briskly. The carbonic acid is immediately absorbed by the water, as may be proved by quickly withdrawing the cork, when the sound of air rushing in to fill the vacuum left by the absorbed gas will be heard. This experiment illustrates the solubility of carbonic acid in water, and one of the modes in which solutions of gases are prepared. Ordinary soda-water is a strong solution of carbonic acid gas, CO_2, in water, H_2O, and when so dissolved, both substances apparently combine and form an acid with the symbol H_2CO_3.

380. (4.) If a little infusion of litmus be poured into a jar of carbonic acid, it will be faintly reddened. If the liquid be then transferred to a flask or test-tube, and heated, it recovers its original blue tint, owing to the escape of the gas. (5.) Carbonic acid does not extinguish flame, for the same reason that nitrogen does—namely, by excluding oxygen—but exerts a positively prejudicial effect on combustion, so as to prevent its occurrence, even when there is as much oxygen present as would otherwise have supported flame. In illustration of this, a mixture may be made at the pneumatic trough of four volumes of carbonic acid with one of oxygen. If a lighted candle be plunged into this mixture, it will be at once extinguished, although the proportion of oxygen present is as great as that in atmospheric air. In like manner, if a lighted tallow candle with a long wick be introduced into carbonic acid, it will be totally extinguished, whereas in nitrogen the wick would have remained red-hot, and might have been fully kindled by being plunged into oxygen.

381. (6.) The density of carbonic acid admits of demonstration by a striking experiment. The weight of the gas is such, that it may be poured like a liquid from one vessel to another, and a candle may be extinguished by letting the gas fall on it. A jar quite full of the gas should be taken for this purpose, and slowly emptied by inclining it till it assumes a horizontal position close to a candle. The jar should not be emptied directly

above the candle, which frequently makes the experiment fail, in consequence of allowance not being made for the impetus in a lateral or horizontal direction, communicated to the gas by the inversion of the jar. If the latter be held a little above, but at the same time to the one side of the flame, and then gently turned over, the candle will not fail to be extinguished.

382. The descent of the gas may be also followed by pouring it into a vessel containing a little lime-water, when the latter becomes chalky. The influence of carbonic acid on respiration does not admit of illustration by experiment unless by the cruel one of introducing a living animal into the gas, when it becomes insensible, and in a short time, if not removed, dies.

383. Carbonic acid does not extinguish life by simply causing suffocation—that is, by cutting off oxygen, as nitrogen does, or water, when an animal is drowned in it. The first-mentioned gas is a positive poison, and occasions death though all the other conditions of life are fulfilled. Thus, air containing a proportion of carbonic acid so comparatively small, that it does not extinguish flame, will nevertheless, if long breathed, extinguish life. This fact cannot be too carefully remembered, as fatal accidents are constantly occurring from ignorance or neglect of it. During the cold season of the year, persons are often tempted to introduce braziers or pans of red-hot charcoal into their apartments. Such contrivances have not chimneys communicating with the outer air, so that the carbonic acid produced of necessity escapes into the room, and rapidly vitiates its atmosphere. Fuel of any kind should never be burned in rooms, unless in fireplaces provided with chimneys, and well ventilated, so that the products of combustion do not accumulate within the apartment. A similar remark applies to the burning of gas as a source of heat in rooms unprovided with the means of ventilation.

384. The following experiments, throwing light on important relations of carbonic acid, should also be tried. The vinous fermentation, as already mentioned, is attended by the production of carbonic acid. Those who can obtain access to a

brewing-vat may have instructive evidence of this in several ways. A candle, let down into a tun containing fermenting beer, will be at once extinguished. A vessel containing lime-water, suspended within it, will soon exhibit the chalkiness characteristic of the action of carbonic acid. An infusion of litmus in the same circumstances will become faintly reddened.

385. On the small scale, a little brown sugar, water, and yeast may be placed together into a gas-bottle, such as that used for preparing hydrogen. If this be put in a warm place, gas will soon be evolved, which may be conducted by means of the delivering tube through lime-water, so as to obtain proof that it is carbonic acid. Or a little fresh beer may be placed in a retort, the beak of which dips into lime-water, and heat applied to the liquid. Carbonic acid will soon be evolved.

386. During animal respiration, carbonic acid is given off abundantly; the proportion in respired air averaging 4 per cent. In proof of this, it is only necessary to blow, by means of a tube, through lime-water, so that the expired air from the lungs may act upon it. A few minutes' blowing will cause a copious precipitate of carbonate of calcium, $CaCO_3$. Carbonic acid is also largely evolved from every lime-kiln ; and when explosions occur in coal-mines, the principal gas formed is carbonic acid, and is then styled *choke damp*, from its suffocating and poisonous properties.

387. Whilst discussing the atmosphere, reference was made to the power of living green plants to decompose carbonic acid when shone upon by the sun. In proof of this, a recently-cut branch, with healthy green leaves upon it, may be placed within a jar of carbonic acid standing over water, and the whole exposed to direct sunlight. After an interval, which will vary according to the brightness of the day, but may amount to one, two, or six hours, the gaseous contents of the jar, when examined, will be found to have lost all power to precipitate lime-water, and instead of extinguishing flame, will support it brilliantly. In short, the carbonic acid, CO_2, has been replaced by oxygen, in consequence of the plant resolving the former into its

constituents, and whilst retaining within itself the carbon, C, leaving the oxygen, O, to go free.

388. Analysis shews that the proportion of carbonic acid in the air of apartments increases in quantity when overcrowding occurs, or where there are not sufficient means for carrying out the wholesome precautions of ventilation. In the great atmosphere itself, however, the air varies very little from year to year, although it is constantly passing in large quantity into the atmosphere as a product of combustion, respiration, fermentation, volcanic action, &c. The carbonic acid is prevented from accumulating, so as to become fatal to animal life on the globe, by this remarkable action of plants, which not only withdraw the poisonous carbonic acid, but replace it by the vital oxygen.

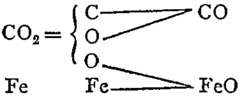
Carbonic Oxide.

Combining weight, 28; *density,* 0·967; *symbol,* CO; *combining measure, two volumes or* □□

[*Old combining weight,* 14; *symbol,* CO.]

389. *Preparation.*—Carbonic oxide does not occur as a natural product, but is known only as produced artificially. It contains an atom less of oxygen than carbonic acid. If the latter, accordingly, be transmitted through a red-hot iron tube, the iron deprives the carbonic acid of half its oxygen, and thereby converts it into carbonic oxide. Thus, forty-four grains of carbonic acid will part with sixteen of oxygen to the iron, and become twenty-eight of carbonic oxide.

$CO_2 + Fe = CO$ and FeO; more fully thus:

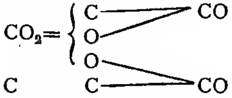


390. Another process is to heat pulverised carbonate of calcium (chalk), mingled with iron or zinc filings, in a gun-barrel, when carbonic acid is evolved, which is in great part

reduced to carbonic oxide; and when the gas is transmitted over quick-lime to absorb the remaining carbonic acid, the gas may be collected in jars, and is carbonic oxide.

391. Carbonic acid may likewise be changed into carbonic oxide, by passing it through a porcelain tube containing red-hot charcoal. The carbonic acid combines with a second atom of carbon, and forms two portions of carbonic oxide.

$CO_2 + C = CO, CO$, or $2CO$; more fully thus:

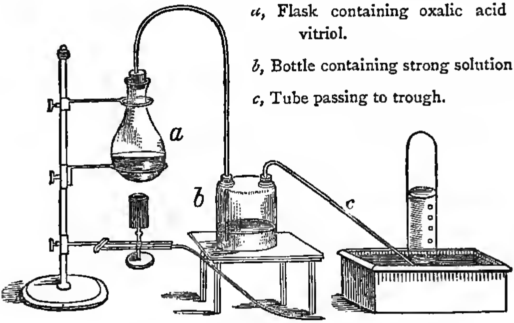


392. Thus, forty-four grains of carbonic acid will combine with twelve of carbon, and form twice twenty-eight of carbonic oxide. This change is constantly occurring in charcoal and coke fires. At the lower and outer part of the choffer or fireplace, the hot charcoal, combining with the oxygen of the air, forms carbonic acid. Much of this ascends through the red-hot fuel in the body of the fireplace, and being thus exposed to a great excess of red-hot charcoal, combines with it, forming carbonic oxide: when this reaches the surface, it burns, producing carbonic acid. The flame of carbonic oxide is blue, but when seen against a ground of red-hot cinders, it appears purple. It is matter of popular observation, that the appearance of such a flame in the fireplace is an indication of frosty weather. A low temperature, such as that of 32°, favours the production of carbonic oxide in the way mentioned, by condensing nearly all the moisture in the atmosphere, so that our fires are maintained at that temperature by almost dry air.

393. For experimental purposes, carbonic oxide is not conveniently prepared in either of the ways mentioned. The deadly poison oxalic acid, which is sold in the shape of small white crystals, when heated in a retort along with strong oil of vitriol, yields a mixture of this gas and carbonic acid. The process needs no particular attention. The gas is not evolved till the temperature of the oil of vitriol has been raised

considerably; but when the gas begins to come off, it is evolved with great rapidity, so that the jars intended to receive it should be standing full of water from the beginning of the process.

394. In this way a mixture is obtained of carbonic acid and carbonic oxide. By pouring into the gas-jars a small quantity of lime-water or solution of caustic potass, the carbonic acid may be absorbed, and the carbonic oxide left; or the mixture of gases may be passed through a solution of caustic potass, which retains the carbonic acid. Fig. 36 shews an arrangement which may be employed for this purpose. The carbonic acid does not interfere with the combustibility of carbonic oxide. A mixture of one ounce of powdered ferrocyanide of potassium (yellow prussiate of potash) with 8 or 10 ounces of oil of vitriol, will yield, when heated, more than two gallons of pure carbonic oxide (576½ cubic inches).



a, Flask containing oxalic acid and oil of vitriol.

b, Bottle containing strong solution of potash.

c, Tube passing to trough.

Fig. 36.

395. *Properties.*—Carbonic oxide is a colourless, invisible gas, having a slight odour, and no taste. It does not support combustion nor respiration. It is more poisonous than carbonic acid, and is one of the causes of the fatal result which attends prolonged exposure to the fumes of burning charcoal. The early symptoms of its action on the animal system are a feeling

of tightness of the head and general oppression. Its most striking property is its combustibility. It burns with a very beautiful blue flame, combining with the oxygen of the air, and forming carbonic acid, CO and $O = CO_2$. The pure gas, if mixed with an equal volume of oxygen, and kindled, detonates sharply, and carbonic acid is produced. Carbonic oxide has never been liquefied. One hundred cubic inches weigh 30·21 grains. It dissolves in water to the extent of 3¼ volumes in 100 of water at 32° F., and 2½ volumes at 60° F.

396. The production of carbonic oxide from oxalic acid is easily explained. This acid consists of 2 atoms of carbon, 3 of oxygen, and 1 of water, C_2O_3,H_2O, so that it contains the elements of one atom of carbonic acid, one of carbonic oxide, and one of water—thus, CO_2,CO and H_2O. When it is heated with oil of vitriol, the sulphuric acid combines with the elements of the water, for which it has a great affinity, and the remainder is resolved into carbonic oxide and carbonic acid, which are liberated, and come off together. The change may be represented thus in symbols:

Before decomposition.................C_2O_3,H_2O and H_2SO_4.
After decomposition..................CO_2,CO and $H_2SO_4 + H_2O$.

COMPOUNDS OF CARBON AND HYDROGEN.

397. The compounds of carbon and hydrogen are not less interesting than those of carbon and oxygen. They are very numerous, and occur alike as solids, liquids, and gases. We can refer, however, only to some of the more important of them, which are of more than ordinary theoretical and practical importance. They are, strictly speaking, organic compounds, but their consideration cannot be delayed till organic chemistry is discussed.

398. Coal-gas depends for its illuminating power on two gaseous compounds of carbon and hydrogen. Each of these is called *carburetted hydrogen;* but as the one of them is nearly

twice as heavy as the other, they are distinguished by the names *light* and *heavy* carburetted hydrogen.

Heavy Carburetted Hydrogen.

Synonym, Olefiant Gas; combining weight, 14; *symbol,* CH_2; *specific gravity,* 0·978; *combining measure or volume,* ☐☐

[*Old combining weight,* 14; *symbol,* C_2H_2.]

399. Heavy carburetted hydrogen is generally called olefiant gas, a name which it derives from its property of forming an oily liquid when it combines with chlorine. Though heavy as a compound of carbon and hydrogen, it is light when compared with other gases. Air being the standard of density, only those gases which are denser than it are called heavy. Olefiant gas, however, is lighter in the proportion of 0·978 to 1·000.

400. This gas is obtained by placing in a capacious retort one measure of spirits of wine and three measures of sulphuric acid (oil of vitriol). Heat is then applied, and in a short time the liquid grows dark, and evolves olefiant gas with great rapidity. It may be collected at the pneumatic trough in the usual way. Its production depends on the following change:

401. Alcohol, C_2H_6O, may be represented as consisting of two atoms of olefiant gas and one of water. When heated with excess of oil of vitriol, the sulphuric acid separates the water from the olefiant gas, and the latter is evolved. Thus in symbols:

Alcohol is C_2H_6O; or $CH_2,CH_2 + H_2O$

so that—

Before decomposition....................C_2H_6O and H_2SO_4.
After decomposition......................CH_2,CH_2 and $H_2SO_4 + H_2O$.

402. *Properties.*—Olefiant gas is colourless and invisible, scarcely soluble in water, but is soluble in alcohol, ether, oil of turpentine, and olive oil. One hundred cubic inches of olefiant gas weigh 30·57 grains. It does not support combustion or respiration; but burns with a dense bright flame, producing during its combustion carbonic acid and water, from the

combination of its carbon and hydrogen with the oxygen of the air. The following experiments may be tried with it:

403. A jar of the gas kindled will shew its combustibility and the brightness of its flame. This is a point of interest, as the illuminating power of coal-gas is in great part dependent on the presence in it of heavy carburetted hydrogen, which is produced during the destructive distillation of the coal. A similar remark applies to the illuminating gas obtained by heating resin and oils and fats, all of which yield much olefiant gas.

404. A strong thick jar is to be filled one-fourth full of the gas, and the remaining three-fourths with oxygen. When a light is applied to this mixture, it occasions a loud explosion, accompanied by the evolution of much heat, but little light.

405. A jar half full of chlorine gas is to be placed on the stool of the pneumatic trough, and filled up with olefiant gas. The gases will rapidly combine, even in the dark, to form *Dutch liquid*, CH_2Cl, which will collect like drops of oil on the surface of the water which ascends within the jar. This experiment illustrates the origin of the name *olefiant*.

406. A similar mixture of one measure of olefiant gas and two of chlorine may have a light applied to it, when it will burn with a smoky flame, and deposit within the jar a large amount of soot. This phenomenon results from the chlorine combining with the hydrogen of the olefiant gas, and rejecting the carbon, the presence of which in the invisible carburetted hydrogen is thus demonstrated.

Light Carburetted Hydrogen.

Synonyms, Marsh Gas, Pit Gas, Fire-damp; combining weight, 16; *symbol,* CH_4; *specific gravity,* 0·5576; □□
[*Old combining weight,* 8; *symbol,* CH_2.]

407. This compound is best known as a natural product, being the gas which issues from the ground in various parts of the world, and admits of being kindled. Stagnant water, in which vegetable matter is decaying, gives off this gas, mixed

with carbonic acid and nitrogen. Hence its name *marsh gas.* It also issues as a product of decomposition from beds of coal, and when it mingles with air, forms the explosive mixture which leads to so many destructive accidents in our coal-pits. It has been called by the miners *fire-damp* or *pit gas,* and it is often evolved in quantity from fissures and cavities in the coal, which are called *blowers.*

408. It can be prepared artificially by strongly heating in a retort a mixture of 40 parts crystallised acetate of sodium, 40 parts solid caustic potass, and 60 parts of quick-lime in powder. The gas is evolved in great abundance, and can be collected over water. A mixture of nearly equal parts of acetate of sodium and hydrate of baryta will equally yield the gas. The acetic acid is a compound of carbon, hydrogen, and oxygen, and the acetate of sodium contains, in addition, water. When heated with alkalis, the hydrogen and oxygen of the water form, with the elements of the acetic acid, carbonic acid and light carburetted hydrogen. The change is illustrated in the following equation:

$$\text{Acetic acid, } C_2H_4O_2 = \left\{\begin{array}{llll} \text{Carbonic acid, 1 atom,} & C & & O_2 \\ \text{Marsh gas, 1 atom,} & C & H_4 & \end{array}\right.$$

$$\begin{array}{lll} \hline C_2 & H_4 & O_2 \end{array}$$

409. *Properties.*—Light carburetted hydrogen is a colourless, invisible, inodorous gas, scarcely soluble in water, which does not support combustion or respiration, but is not poisonous. One hundred cubic inches weigh only 17·41 grains. It burns with a white flame, but has not so great an illuminating power as olefiant gas. During combustion, the light carburetted hydrogen, CH_4, combines with the oxygen of the air to form carbonic acid (*choke-damp* of the miners) and water, and when mingled with twice its volume of oxygen, or ten times its volume of air, it detonates powerfully.

Coal-gas.

410. Coal-gas is not a definite chemical compound, but a mixture of many unlike substances, obtained by exposing coal to a red heat in gas (clay and iron) retorts. The coal preferred for this purpose is cannel coal, the bright shining variety which does not soil the fingers. When heated in a retort, it yields a variety of products, among which three are specially important: *1st*, Tar, a highly complex mixture of various naphthas and other compounds of carbon and hydrogen. *2d*, Ammonia, in combination with carbonic acid, hydrosulphuric acid, &c. *3d*, Light and heavy carburetted hydrogen. Besides these, there are variable proportions of hydrogen, nitrogen, carbonic oxide, carbonic acid, hydrosulphuric acid, prussic acid, &c.

411. The gas, as it issues from the retorts, is received into a large horizontal iron chamber, called the hydraulic main, half full of liquid, and from thence passes through a series of large iron siphons, named the condensers, kept cool, in which it deposits the tar and ammoniacal liquor. The gas is then made to traverse vessels containing milk of lime, or through a chamber with dry slaked lime. The lime absorbs the useless carbonic acid and noxious hydrosulphuric acid, and the gas is then collected in large metallic reservoirs, called gas-holders, from which the pipes which distribute it proceed. Ordinary coal-gas, in spite of the purification to which it is subjected, contains a variable amount of different substances, some of which are of no service, and others are positively prejudicial. It consists essentially of about fifty or sixty per cent. by volume of light carburetted hydrogen, and from twelve to fifteen per cent. of olefiant gas, along with carbonic oxide, hydrogen, and nitrogen. The carburetted hydrogens are the only valuable constituents of coal-gas, so far as its application to the production of light is concerned.

DAVY LAMP.

412. The dangerous explosions which occur when a light is applied to a mixture of fire-damp and air, have already been referred to, but the discussion of the methods by which, on the large scale, they may be prevented, has been postponed till the nature of coal-gas should have been made known, because the experiments we are about to mention can be much more conveniently tried with coal-gas, of which light carburetted hydrogen is the chief constituent, than with fire-damp itself.

413. To prevent accidents in coal-pits, Sir Humphry Davy devised a very ingenious lamp, which goes by the name of the Davy or Safety Lamp, and is intended to furnish the miner with a source of light which shall have no power to kindle fire-damp.

414. Fire-damp alone does not burn or explode. It must be mingled with air before either of these phenomena can shew itself. If, however, it be mixed with too much air, explosiveness is again lost. Detonation occurs most powerfully when the fire-damp is mixed with from eight to ten times its volume of air. If the proportion of air be diminished to three or four times that of the fire-damp, or be increased to more than fourteen times its measure, explosion does not happen. Where the volume of air is very small, an amount of oxygen sufficient to burn the fire-damp is not furnished. Where the quantity of air, on the other hand, is too large, it prevents the spread of flame by conducting away heat, and preventing the temperature rising high enough to inflame the combustible gas.

415. The fact last referred to is taken advantage of in the construction of the Davy lamp. Fire-damp cannot be kindled unless it be raised to a white heat, unlike pure hydrogen, which takes fire at the lowest visible red heat. When an explosive mixture, accordingly, collects in a coal-mine, in consequence of the fire-damp issuing from the seams of coal, and mingling with the air, if it meets a naked flame, such as that of a candle which is at a white heat, explosion at once happens. The object of

the Davy lamp is to enable the miner to employ artificial light in the midst of such an explosive atmosphere without any risk of kindling it.

416. This is done in the following way: The safety lamp consists of a small cylindrical oil-lamp, differing in no respect from those in ordinary use, except that a brass wire passes through a canal traversing the lamp from below, and is bent over close to the wick where it issues at its surface, so that by turning this wire, the wick can, to a certain extent, be trimmed without uncovering it (see fig. 37). The peculiarity of the lamp consists in a cover or cage of wire-gauze, which is screwed on to the top of the lamp after the wick is lighted. This wire-gauze cover is made double at the top, for the sake of strength, but a single layer of the gauze, so long as it is entire, renders the lamp quite safe in an explosive atmosphere.

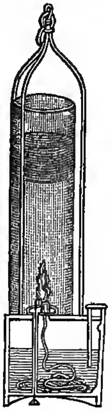


Fig. 37.

417. When the lamp, as we have described it, is carried into an explosive mixture of light carburetted hydrogen and air, no explosion happens. The mixture of gases traverses the apertures in the gauze, and burns around the wick, but the flame does not travel *outwards* through the meshes of the wire-work, so as to kindle the mass of fire-damp without. The lamp makes explosion impossible, not, as is often imagined, by preventing the fire-damp reaching the flame within the cage, but by preventing that flame from reaching the fire-damp without. The light is put out whilst in the very act of traversing the wire-gauze, in consequence of the latter, which is an excellent conductor of heat, carrying that away, and so causing the temperature of the flame to fall below the white heat necessary for kindling fire-damp.

418. A piece of wire-gauze, in truth, consists essentially of a multitude of metallic tubes, or canals, placed side by side (see fig. 38). These tubes are exceedingly short, so that we are apt to forget that they are tubes at all; but canals they

certainly are, with walls, comparatively speaking, very thick, and consisting of a metal, one of the best conductors of heat. In the Davy lamp, as we have described it, the flame is at one end of each of these metallic tubes, and the mass of explosive mixture ready to be fired is at its other extremity. The tube, too, is filled with the explosive mixture, which, like a train of gunpowder, must be kindled, otherwise the flame will not be propagated through the tube.

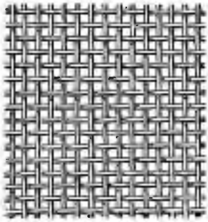


Fig. 38.

419. The flame, however, never can succeed in traversing the canal, for a portion of the explosive mixture set fire to at one end of it is unable to kindle the portion lying next it in the canal, in consequence of the sides of that canal appropriating to themselves the caloric which otherwise would serve to kindle the gas, but which is unable both to inflame it and to heat the metal, and is compelled, in virtue of the high conducting power of the metal, to raise its temperature rather than that of the gas. The following simple experiments will illustrate the facts just explained:

420. A small metallic spiral may be formed by coiling iron wire round a pencil (fig. 39). If this be gently placed, like an extinguisher, over the wick of a burning candle, which it should be large enough not to touch, the light will go out; the burning vapour of the wax or tallow being unable to maintain itself at a white heat when in contact with a mass of metal.

Fig. 39.

421. A piece of wire-gauze is to be pressed down on the flame of a candle, or, still better, on a jet of burning gas (fig. 40). It will be found to intercept the flame, which will burn only on the lower side of the gauze.

422. That the gauze acts by arresting the flame, not by stopping the passage of the gas, may be proved by pressing the wire-gauze over a gas-flame, and then applying a lighted match

to the upper surface. It will set fire to a volume of combustible gas, which has all the while been ascending through the meshes of the wire-work, but which the flame below was unable to kindle.

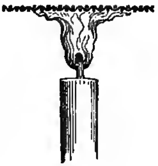


Fig. 40.

423. A still more striking experiment is to lay the wire-gauze on a nozzle from which coal-gas is issuing, and then to light the gas on the upper surface of the wire-work. If the gauze be then raised gently, it may be lifted to the extent of two inches or more above the nozzle, carrying a tongue of flame with it, fed by a column of gas ascending from the nozzle, but which is not kindled by the burning gas above.

424. A piece of camphor may be laid on a sheet of wire-gauze and kindled. It will burn with a dark, smoky flame, at the same time melting, and dropping through the gauze. But though the drops are as combustible on the lower as on the upper surface of the wire-work, the flame will not descend through the meshes, or kindle the melted camphor below.

425. For the following experiment a Davy lamp, if it can be procured, should be employed. In the absence of it, a cylindrical cage may be constructed of wire-gauze, and laid over a lighted candle, or an oil or spirit lamp. A jet of coal-gas is now to be directed, by means of a flexible tube, against the cage, so as to pass through its meshes, and reach the flame. It will take fire and burn within the cylinder, but the extremity of the flexible tube may be pressed close against the wire-gauze without the flame being communicated to the jet of gas. If the stream be made to envelop the flame of the lamp in large quantity, the light will go out, in consequence of the exclusion of air; a phenomenon occasionally witnessed in coal-pits, but forming no essential objection to the value of the lamp, as it is only witnessed when the volume of fire-damp is so large that the atmosphere of the pit is irrespirable.

426. The Davy lamp appears to afford a complete protection against explosion, except where a very rapid current of fire-damp,

issuing, as it frequently does, with great force from cavities in the coal where it has been pent up, impinges against the lamp. In these circumstances, it may hurry the burning gas so swiftly through the wire-gauze, that the latter has not time to lower its temperature below the explosive point.

427. When an explosion happens in a coal-pit, much carbonic acid is produced, along with water, in consequence of the carbon and hydrogen of the fire-damp combining with the oxygen of the air. This carbonic acid is called by the miners the 'after-damp,' or 'choke-damp;' and it is as great a cause of mortality at an explosion as the mere mechanical violence occasioned by the detonation.

STRUCTURE OF FLAME.

428. The artificial lights which we employ—such as lamps, candles, and gas flames—all owe their luminosity to the combustion of compounds of carbon and hydrogen. It is convenient here, accordingly, to discuss the nature of flame, the cause of its luminosity, and the chemical principles involved in the construction and employment of the blowpipe.

429. By the word flame, we denote gas or vapour raised to so high a temperature that it emits light as well as heat. All flames are not equally hot, but their temperature is always high, and when at its maximum, exceeds that of solid bodies at an ordinary white heat.

430. The flame of a lamp, or candle, or simple gas-jet, consists of a hollow cone, in the centre of which there is no combustion. If one of these flames, especially that of a candle, which illustrates the phenomena best, be examined closely, it will be seen to have a triple structure. Directly above the wick, a dark or non-luminous space is visible. This is surrounded by a shining envelope, or luminous cone, which deposits soot upon a cold body introduced into it. External to this, a second cone may with difficulty be traced, having far less luminosity than the first, but possessing a very high temperature.

431. The central space appears dark only by contrast with the luminous cone which surrounds it. It consists, in reality, of transparent, invisible compounds of carbon and hydrogen, which are constantly rising in vapour from the wick. This may be proved in two ways: 1. If a glass tube, open at both ends, be held obliquely in the flame of a candle, with its lower extremity in the dark central space above the wick, it will conduct away much of the combustible vapour, which may be kindled at its upper end in the way shewn in the accompanying figure (fig. 41). 2. If a piece of fine wire-gauze be pressed down on the candle-flame, and this be looked at from above, through the gauze, whilst combustion is going on only below, the flame will appear like the mouth of a tube, the walls of which are luminous.

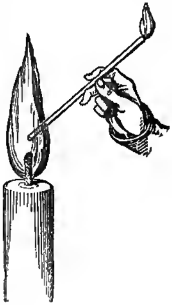


Fig. 41.

432. The unburned gas which occupies the centre, and, as it were, fills the luminous tube, rises through the wire-gauze, and, as mentioned under the Davy lamp, may be kindled at its upper surface. If, moreover, a lighted candle be held between the eye of the observer and a sheet of paper or other white object, the latter will be seen through the apparently dark central space (fig. 42). This flameless portion of the flame may be distinguished by the title of *the area of no combustion.*

433. The luminous cone which envelops the dark space is characterised as *the area of partial combustion.* In it a limited amount of oxidation occurs, in virtue of the oxygen of the air penetrating to that depth, so as to combine with the hydrogen and carbon; but the amount of oxygen which does reach these combustibles is not sufficient to oxidise both, and is almost entirely spent in converting the hydrogen into water.

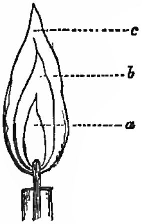


Fig. 42.

a, Area of no combustion.
b, Area of partial combustion.
c, Area of complete combustion.

434. The outer cone is named *the area of complete combustion*, because in it the entire oxidation of the carbon is effected, and it is resolved into carbonic acid; whilst as a result of this, a high temperature is produced.

435. These three areas are not sharply marked off by visible lines of demarcation, but, on the other hand, shade away into each other; and in the case of a simple combustible gas, such as hydrogen, we pass by imperceptible gradations from the central space of no combustion to the outer one of complete oxidation. In the flame, however, of carburetted hydrogens (that is, of any gaseous or vaporous compound of carbon and hydrogen), an additional phenomenon appears, which accounts for the highly illuminating power of compounds of this class, as compared with the simple combustible gases.

436. Oxygen has a much greater affinity for hydrogen than for carbon; so that, when presented in small quantity to a compound of carbon and hydrogen, it is entirely (or almost entirely) spent in oxidising the hydrogen, whilst the carbon separates in the *solid* form. This is the cause of the deposition of soot on bodies introduced within the inner luminous cone, and is taken advantage of, as we have mentioned already, in the preparation of lampblack. It accounts also for the great illuminating power of the area of partial combustion.

437. Its luminosity results from the fact, that whilst the hydrogen only of the combustible is burned by the oxygen of the air which penetrates to that depth, the high temperature produced by the burning hydrogen raises to a white heat the solid, unburned carbon, which, like the lime in the lime-ball light, is the true source of the brightness of the flame. In the outer area the white-hot carbon meets abundance of oxygen, and combining with it, raises the temperature of the surrounding air to some considerable distance from the visible flame.

438. The highly illuminating power of compounds of carbon and hydrogen is thus traced to the fact, that their hydrogen and carbon do not burn simultaneously, but successively, and in such a way that the one heats the other white-hot. It is

quite possible to make them burn synchronously or contemporaneously; but when they do, the light they evolve is extremely feeble—not greater, indeed, than that of pure hydrogen. Thus olefiant gas, and light carburetted hydrogen, which, when kindled at a jet, or the mouth of a jar, burn with highly-luminous flames, exhibit scarcely any luminosity when detonated with air or oxygen. In the latter case, the carbon burns as fast as the hydrogen.

439. The same fact may be illustrated very simply with coal-gas, by placing over a jet from which it is issuing, a chimney or hollow cylinder, covered at the top with wire-gauze. When the gas is turned on, it ascends within the chimney, and mixes with air before passing through the gauze. Another arrangement is to take a Bunsen lamp (fig. 43), where the gas issuing from an ordinary jet is allowed to mingle with air, which enters by small holes perforated in an outer shield or tube. By a little adjustment of the stop-cock, the gas may be supplied in such quantity, that it shall be mixed with enough of air to oxidise, when it is kindled, both its carbon and hydrogen. On lighting the gaseous mixture above the wire-gauze in the first case, and at the top of the outer tube in the Bunsen lamp, it burns with a pale-blue flame, somewhat like that of carbonic oxide, and not more illuminating.

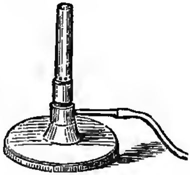


Fig. 43.

440. From these experiments, it appears that it is not the mere presence of carbon in coal-gas, or in oil, or tallow, that makes their flames luminous, but the fact, that the carbon in a solid state is heated white-hot during their combustion. All highly-luminous flames, indeed, contain white-hot *solid* matter. The lime-ball light furnishes evidence of the converse of this—namely, that the most feebly-luminous flame may be rendered highly illuminating by introducing within it a solid which it may heat.

441. In further evidence of this, it may be noticed that where a combustible, as well as the product of its combustion

in air or oxygen, is a *solid*, much light is always evolved; but where the inflammable and its oxide are gases, or liquids, the flame is very feeble. Thus iron burned in oxygen, and the metals generally, when undergoing rapid oxidation, are highly luminous; for the metals are solids, and their oxides are also solids. For the same reason, solid phosphorus, which forms solid phosphoric acid when it burns, evolves an intense light; but sulphur, which, though solid, yields, when burned, a gas (sulphurous acid, SO_2), is but feebly luminous; and hydrogen gas, the product of whose combustion is also a gas, or vapour (water as steam, H_2O), is still less illuminating.

THE BLOWPIPE.

442. The blowpipe (figs. 44 and 45) consists simply of a glass or metallic tube, with a mouth-piece (*a*) at one extremity, and a nozzle (*b*) of small bore at the other, through which a stream of air can be forced across the flame of a lamp or candle (fig. 46). By means of it air is furnished to what in an ordinary upright flame is the central area of no combustion, so that oxidation goes on both in the centre of the flame and along its outer border.

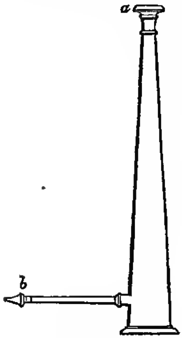


Fig. 44.

Fig. 45.

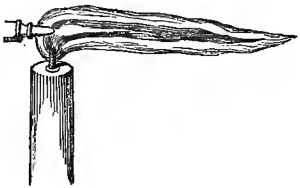


Fig. 46.

443. When the blowpipe flame is examined, it is seen to

consist of two elongated cones of a bluish shade (fig. 47). Between these cones there is a space, corresponding in some measure to the middle area of partial combustion of an upright flame, but at a much higher temperature. This is distinguished as the *reducing* portion of the flame, or, more briefly, as the *reducing flame* of the blowpipe; because the large amount of white-hot carbon which it contains enables it to reduce—that is, deprive of oxygen—the great majority of metallic oxides, so that their oxygen forms carbonic acid, and the metal separates.

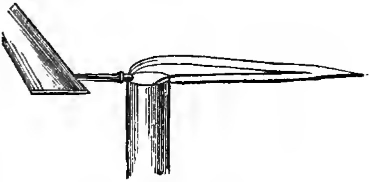


Fig. 47.

444. The tip or point of the outer cone, and to a certain extent its whole external border, is called the *oxidising* flame of the blowpipe; because metals, and other easily-oxidised bodies, are rapidly converted into oxides when held in this portion of the flame, in consequence of the high temperature to which it elevates the air immediately in contact with it. The term oxidising *flame*, in truth, is not strictly correct; for it is the heated air, and not the luminous flame, which produces the oxidation; and bodies must be held a little in front of the visible flame in order to secure their oxidation.

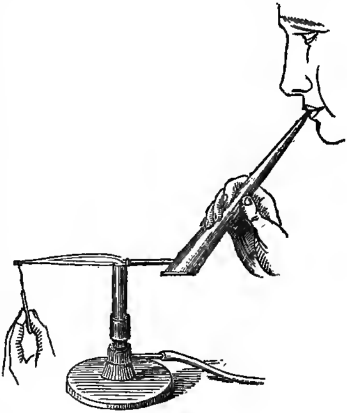


Fig. 48.

445. When the blowpipe is used, the body to be subjected to its action is held in a loop of platinum wire (fig. 48), or placed in a small cup of clay, or in a cavity in a piece

of charcoal. A stream of air is then sent through the blowpipe from the mouth, in such a way as to supply the air in an unbroken current. This is effected by closing the lips upon the mouthpiece of the blowpipe, distending the cheeks as a trumpeter does, and then blowing; whilst, without letting the cheeks collapse, air is simultaneously, or at short intervals, drawn through the nostrils.

446. The method of blowing is easily learned. The beginner fails for a time, in consequence of supplying the current from his lungs, the quantity of available air in which is soon exhausted, so that the stream intermits, and the blower is out of breath. To secure an unbroken stream, air must at the same time be drawn in by the nostrils, so as to maintain respiration, and be expelled by the mouth to feed the current. The cavity of the mouth is kept distended, to act as a reservoir, like the sack of a bagpipe, whilst, by a slight compressing action of the muscles of the cheeks, partially diminishing the capacity of that reservoir, the air is propelled along the blowpipe.

447. In learning the use of this instrument, the beginner should not blow fiercely. It is continuity, not rapidity, of current that is chiefly desired; and as soon as he can blow, however gently, and at the same time take a breath by the nostrils, he has mastered the whole difficulty of the blowpipe.

448. From what has been stated as to the structure of the blowpipe flame, it will be understood that it makes the greatest possible difference as to the effect it produces upon any body introduced into it, whether that substance be exposed to the reducing or the oxidising flames. These flames may be distinguished, as already mentioned, by their positions, the reducing flame being the inner, and the oxidising the outer; but the inexperienced manipulator will have difficulty at first in producing the flames sharply defined from each other, so as to be able to recognise them by the difference in their positions. When he is directed, however, to expose a body to the oxidising flame, he will find it sufficient to hold it a little in front of the

visible point or tip of the flame; and when the reducing flame is prescribed, it will suffice to hold the substance well back within the flame, so that it shall be enveloped by it.

449. In illustration of the opposite powers of the blowpipe flames, the student may place a fragment of metallic lead on a piece of charcoal, and expose it to the oxidising flame. The lead will rapidly become converted into its protoxide, PbO, and melt into a transparent globule. If this be now carried back within the flame, so as to be exposed to its reducing portion, the oxygen will be rapidly removed, and the lead reappear in its metallic state. This oxidation and deoxidation may be obtained alternately with the same piece of metal any number of times.

450. In like manner, if a piece of white flint-glass be exposed to the reducing flame, the oxide of lead which it contains is deprived of its oxygen, and the glass acquires a brilliant, black, metallic coating, which renders it opaque. It may be rendered transparent again by exposing it to the oxidising flame.

451. Experiments similar to those first mentioned may be made with other metals besides lead—such as copper, zinc, bismuth, antimony; but none of them do so well as lead.

BORON.

Combining weight, 11; *symbol,* B; *volume,* □; *density,* 2·68.

452. Boron is an element having considerable analogy to carbon and silicon, and can be obtained as an amorphous olive-green powder; in transparent crystals of a brown colour and extreme hardness, much resembling the ordinary carbon diamond; and in scales resembling graphite or plumbago. It is sparingly diffused in nature, and occurs only in combination with oxygen as boracic acid, B_2O_3, which is found uncombined in the lagoons of Tuscany and other volcanic districts, and in union with soda forming the salt borax, or tincal,

which is brought to this country from Thibet and China, and lately from California. A borate of lime and magnesia is also obtained from South America.

453. Boron may be obtained by heating its only oxide, boracic acid, along with the metal potassium, or sodium, when amorphous boron is obtained; or still better, with aluminum, in a crucible, when the crystals or boron diamonds are formed, and at the same time some of the graphitoid boron in scales. In either case the metal unites with the oxygen of the boracic acid, B_2O_3, and sets free the boron. It can therefore be obtained in three states, as an olive-brown powder, and in minute crystals which resemble the real carbon diamond much in physical properties, as also in their power of reflecting light, and in scales resembling ordinary graphite. When strongly heated in air or oxygen, it burns, forming boracic acid.

Boracic Acid.

Symbol, B_2O_3; *combining weight*, 70.

[*Old symbol*, BO_3; *combining weight*, 35.]

454. This acid is generally obtained by adding sulphuric acid to a hot aqueous solution of the commercial salt borax, the biborate of sodium, $Na_2B_4O_7 + 10H_2O$ [old symbol, $NaO,2BO_3 + 10HO$]. The sulphuric acid, SO_3, combines with the soda, Na_2O, forming sulphate of sodium, Na_2SO_4; and the boracic acid, which is sparingly soluble in cold water, separates in crystals, $B_2O_3 + 3H_2O$ [old symbol, $BO_3 + 3HO$], as the liquid cools.

455. Boracic acid melts when heated, losing the water which is generally associated with it, and forming, as it cools, a transparent, colourless, glassy mass. Its taste is only faintly sour, and it does not fully redden vegetable blues, but changes them only to a pale purple, as the analogous body, carbonic acid, does.

456. It dissolves in alcohol, and the solution, when set fire to, burns with a beautiful green flame. If a crystal of borax or tincal be crushed to powder, covered with oil of vitriol, and

alcohol be poured over the acidulated salt, and kindled, the characteristic green flame will be seen. When hydrochloric acid is added to any substance containing boracic acid, and yellow turmeric paper be dipped in the acidulated mixture and dried, a deep red colour is produced on the paper.

457. The most important compound of boracic acid is borax, $Na_2B_4O_7 + 10H_2O$ [old symbol, $NaO,2BO_3 + 10HO$]. It is employed in the arts as a constituent of the finer varieties of glass, and in forming glazes for porcelain. It is likewise used in soldering metals, and in medicine.

458. Borax is also of much service to the analytical chemist, in consequence of its power to dissolve metallic oxides, which, in the majority of cases, form coloured glasses by combination with the boracic acid. The tints of these compounds differ according to the metallic oxide present in them, so that their colours supply an accurate and easily-applied method of identifying compounds before the blowpipe.

459. In illustration of this, the following experiments may be tried: 1. A fragment of borax is to be placed in a cavity in a piece of charcoal, and exposed to the blowpipe flame till the water of crystallisation is expelled. A drop of solution of nitrate of cobalt is then to be let fall on the anhydrous salt, and this is to be treated a second time in the outer or oxidising flame of the blowpipe, till it fuses into a clear globule. On allowing it to cool, it will be found to exhibit a deep-blue colour which is characteristic of cobalt. 2. If a similar experiment be made with chloride of manganese, the globule or bead of borax will be of a violet colour; if a salt of the metal chromium be employed, it will be green; and if one of the suboxide of copper or of gold be used, the borax-glass will be a fine red.

SILICON.

Synonym, Silicium; symbol, Si; *combining weight,* 28;
combining volume, □; *density,* 2·49.
[*Old combining weight,* 14; *symbol,* Si.]

460. *Distribution.*—Silicon, like boron, does not exist in nature uncombined, but its oxide, SiO_2, silica, silicic acid, or silicious earth, is the chief constituent of the crust of the globe. It forms, as it were, the stony skeleton of the earth. Thus sand, sandstone, and quartz are pure silica; granite and gneiss consist chiefly of silica; and a multitude of minerals, which by their aggregation form other rocks, such as trap, basalt, lava, &c. are silicates—that is, compounds of silicic acid with metallic oxides. Silicon, indeed, is as abundant an element in the mineral world as the analogous carbon is in the vegetable kingdom.

461. Silicon may be obtained in the three conditions of amorphous, graphitoid, and crystalline: 1*st*, As an amorphous powder, by heating the silico-fluoride of potassium with an excess of potassium, when a soft, dark-brown powder is obtained without any metallic lustre, and which burns brilliantly in air, forming silicic acid, SiO_2. 2*d*, As a graphitic form (resembling the graphite of carbon), by subjecting the amorphous silicon to intense heat in a platinum crucible, when it becomes much more dense, and withstands the action of fire without burning even at very high temperatures. The same variety may be obtained in the form of minute plates, with a brilliant metallic lustre, by acting upon a silicide of aluminum by hydrochloric acid. 3*d*, As a crystalline substance by passing the vapour of chloride of silicon over heated aluminum, when the volatile chloride of aluminum is formed, and crystals of silicon are obtained which are transparent, exhibit a red colour, cut glass, and possess other properties similar to the ordinary diamond.

Silica or Silicic Acid.

SiO_2.

462. Silicic acid is the only known oxide of silicon. Rock-crystal, white sand, or calcined flints, may be taken to represent pure silica. It may also be obtained from many of its compounds in the following way: The mineral containing it (such as felspar, granite, or sea-sand) is reduced to fine powder, and mingled with three or four times its weight of a mixture, in equal parts, of carbonate of potassium and of sodium. The whole is heated in a platinum crucible till it fuses into a glassy mass. The contents of the crucible are then boiled with water, to which hydrochloric acid in excess is afterwards added, and the whole evaporated to dryness.

463. During the fusion, the silica enters into combination with the potass and soda (liberating the carbonic acid), and abandoning any oxide with which it was previously in union. The hydrochloric acid sets the silicic acid free, combining with the alkalies to its exclusion, and at the same time uniting itself to whatever oxides were originally present in the mineral. The separated silica is to some extent dissolved by the diluted acid, but after the evaporation of the liquid to perfect dryness, it loses its solubility, and when acidulated water is poured upon the desiccated mass, it dissolves everything but the silica, which it leaves untouched.

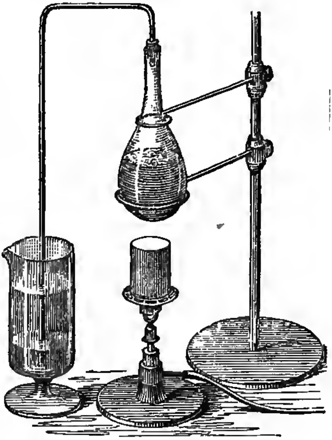


Fig. 49.

464. Another method of preparing silica in a fine state of division is to take a mixture of equal parts of powdered fluorspar and glass, and introduce

these into a flask, where they are drenched with sulphuric acid. A bent tube is introduced into the flask, the other end of which dips into a receiving vessel, containing enough mercury to cover the end of the tube, and thereafter filled up with water (fig. 49). The gas evolved is decomposed when it enters the water, and silica in a gelatinous form is separated. When the gelatinous silica is washed with water and dried, it is obtained as a very fine and light powder, which can be blown about with a breath of wind.

465. *Properties.*—Silica is a snow-white, gritty powder, which, after being strongly heated, is quite insoluble in water, acids, and indeed most liquids. It is infusible by the most powerful wind-furnace, but melts when exposed to the intense flame of the oxyhydrogen blowpipe. Its sp. gr. is 2·642 when crystallised, and 2·2 to 2·3 when in the amorphous or non-crystalline state. In spite of its insolubility in water in its ordinary gritty state, yet in the gelatinous form it dissolves in that liquid. Natural waters contain soluble silica, some of them in large quantity. The solution is tasteless, and has no action on vegetable colours, so that silicic acid is deficient in two of the characteristic properties of the strong acids. Nevertheless, at high temperatures, it combines with bases with the utmost readiness, displacing every acid more volatile than itself.

466. A very large number of minerals are silicates, consisting of silicic acid, united with a variety of metallic oxides, such as those of iron and of manganese, as well as alumina, lime, magnesia, potass, and soda. The important artificial products, glass, porcelain, and stoneware, are combinations of silicic acid with different oxides. Clay is the silicate of aluminum, and is the constituent of common earthenware. China contains, in addition, lime, potass, soda, &c., besides excess of silica, and frequently also fusible compounds of boracic and phosphoric acids.

467. There are two species of glass, the one consisting of silica united to an excess of potass and soda, and characterised by being soluble in water; the other, and familiar species,

which is totally insoluble in water, and the immense majority of reagents, contains excess of silica, and is, besides, a combination of several silicates with each other, as silicate of sodium with silicate of calcium, or silicate of potassium with silicate of lead.

SULPHUR.

Combining weight, 32 ; *symbol,* S ; *synonym, Brimstone ; specific gravity, prismatic variety,* 1·982 ; *octohedral,* 2·045 ; *specific gravity as vapour at* 900°, 6·617, *combining measure,* $\frac{1}{3}$*d volume ; at* 1900°, *density* 2·230, *and combining measure* □

[*Old notation,* S, *and combining weight,* 16.]

468. *Distribution.*—Sulphur occurs abundantly free, chiefly in volcanic districts, where, as on the flanks of Etna in Sicily and Hecla in Iceland, it presents itself in large veins, from which it is quarried. It is also extensively diffused through the globe, in combination with the metals, so that the chief ores of silver, lead, zinc, antimony, &c., are sulphides. Much also occurs in combination with iron, forming a well-known mineral, iron pyrites, which is the bisulphide of iron, FeS_2.

469. In the state of sulphuric acid, united with bases, sulphur also occurs frequently. Heavy spar, for example, and gypsum, both abundant minerals, are respectively the sulphate of barium and the sulphate of calcium. The sulphates of magnesium, copper, iron, and several other metals, are also found native. It is present in all plants, and is an essential and important ingredient of animals. In the latter, as well as in plants, it exists in a peculiar state of combination, of which a good example is furnished by white of egg, the familiar effect of which in blackening a silver spoon is owing to the sulphur it contains.

470. Sulphur occurs in commerce in two states—*roll* sulphur, which is the substance in a solid state shaped into cylinders by casting it in suitable wooden moulds; and *flowers* (not flour) of sulphur, which present this body in the shape of a fine

crystalline powder, procured by condensing its vapour, in imitation of the natural process by which water-vapour changes into snow. Flowers of sulphur are also called sublimed sulphur, and are purer than the substance in rolls. The common name for sulphur is brimstone.

471. *Properties.*—Ordinary sulphur is a lemon-yellow, brittle solid, crystalline in structure, and exhaling a peculiar odour when rubbed. It is about twice as heavy as water, in which it is insoluble, but it dissolves in other liquids, such as oil of turpentine and the fixed oils, as also benzol, but best of all in bisulphide of carbon, which takes up one-third its weight of sulphur, and from which solution it may be procured by evaporation, in semi-transparent, amber-yellow crystals of the form of an octohedron, with a rhombic base.

472. When sulphur is heated till it fuses, and is allowed partially to cool, crystals of the oblique prismatic form are obtained. A roll of sulphur held in the warm hand near the ear, will be heard to emit a peculiar crackling sound; and if the difference between the temperature of the sulphur and the hand be considerable, will split into pieces. These phenomena are owing to the bad and unequal power of conducting heat which characterises sulphur, in consequence of which it expands in one direction more than in another when heated, and, as a result, has the more expanded portions separated, and, as it were, torn from the colder and contracted ones.

473. Pieces of roll sulphur placed in a glass flask, and heated, will melt at 239°, and form, up to the temperature of 250°, a clear, thin, limpid, yellow liquid. If poured in this state into water, it rapidly congeals into a yellow crystalline solid. If, on the other hand, after it has melted, the heat be still continued, the liquid grows darker in colour, and much thicker in consistence, so that between 430° and 480° it resembles in appearance treacle, and is so viscid and sluggish in its movements, that it is some time before it begins to flow from a vessel containing it, after that has been inverted.

474. If liquid sulphur be poured into water whilst in this

treacly condition, it consolidates into a soft, elastic substance, of a dark-yellow or pale-brown colour, much resembling caoutchouc in some of its properties, and unlike ordinary sulphur. It is insoluble in bisulphide of carbon and other liquids, and can be drawn out into long elastic threads like india-rubber, but in a few days it returns to the hard crystalline state. The elastic form of sulphur has a specific gravity of 1·957, and is an allotropic modification of ordinary brittle sulphur. When the treacly liquid is heated to about 500°, it grows thin and liquid again, though not so fluid as it was at a lower temperature; and when it reaches about 836°, it passes into ebullition. It will then be observed to give off a deep yellow vapour, which condenses on cold bodies into solid sulphur, and is highly combustible. Sulphur has also been obtained in other allotropic forms, such as *black* sulphur and *red* sulphur.

475. The inflammability of sulphur or brimstone is well known. It takes fire when heated in the air to a temperature between 450° and 500°. The product of the combustion is sulphurous acid. When the vapour of sulphur is conducted through a porcelain tube containing red-hot charcoal, it combines therewith, and forms a highly volatile ethereal liquid known as the bisulphide of carbon, having the symbol CS_2.

Sulphurous Acid or Sulphurous Anhydride.

Combining or atomic weight, 64; *symbol*, SO_2; *specific gravity*, 2·247; *combining measure*, □□

[*By old notation*, SO_2; *combining weight*, 32.]

476. When sulphur is kindled, it burns with a blue flame, and evolves a highly characteristic odour, distinguished as that of burning brimstone, which is not the smell of sulphur itself, but that of its oxide, sulphurous acid or sulphurous anhydride, SO_2.

477. If the experiment of burning sulphur in oxygen described under that gas be repeated, the phenomena described in the preceding paragraph will be witnessed still more fully, and the

production of an acid (namely, sulphurous) may be demonstrated by pouring infusion of litmus into the jar in which the sulphur has been burned. When oxygen is thus converted into sulphurous acid, it undergoes no change in volume, although it doubles its weight; thirty-two grains of oxygen combining with as many of sulphur to form sixty-four of sulphurous acid.

78. Sulphurous acid is generally prepared from sulphuric acid in the following way: Quicksilver is heated in a retort with an equal weight of oil of vitriol till effervescence occurs. The mercury deprives the sulphuric acid of one-third of its oxygen, thereby reducing it to the state of sulphurous acid. This comes away as a gas, and may be collected like other gases, but not at the water-pneumatic trough, owing to its solubility in that liquid. The decomposition may be thus represented in symbols:

$$SO_3 + SO_3\text{, and } Hg = HgSO_4 + SO_2.$$

479. The mercury combines with oxygen, derived from the sulphuric acid, to form oxide of mercury, thereby converting sulphuric acid into sulphurous acid, and the oxide of mercury afterwards unites with undecomposed sulphuric acid to form sulphate of the oxide of mercury. Two stages, therefore, may be recognised in the decomposition.

First stage......................$SO_3 + Hg = SO_2$ and HgO.
Second stage....................$SO_3 + HgO = HgSO_4$.

480. In the preceding diagrams, the water of the oil of vitriol, which only plays a secondary part, and does not directly affect the change, has not been inserted. Copper turnings may be employed instead of mercury when the sulphate of copper, $CuSO_4$, is formed. A cheaper and more convenient method for the preparation of the gas, is to heat charcoal and sulphuric acid (oil of vitriol) together in a retort, when a mixture of sulphurous anhydride and carbonic anhydride is given off. Thus the change may be represented in symbols:

$$SO_3 + SO_3 \text{ and } C = CO_2 \text{ and } 2SO_2.$$

481. *Properties.*—Sulphurous acid, or rather sulphurous anhydride, is a colourless, invisible gas, having the odour and taste of burning brimstone. It extinguishes flame, is quite irrespirable, and indeed poisonous. Water dissolves more than forty times its volume of the gas. One hundred cubic inches weigh 68·69 grains.

482. The weight of the gas, which is more than twice as heavy as air, enables us to dispense with the costly mercurial trough in examining most of its properties. A bottle or jar may be filled with the gas by bringing a glass tube connected with a retort (fig. 50), or other arrangement, such as a flask, from which sulphurous acid is issuing, to the bottom of the vessel intended to receive the gas. The gas then fills the bottle or jar from below, chasing out the air before it as it ascends.

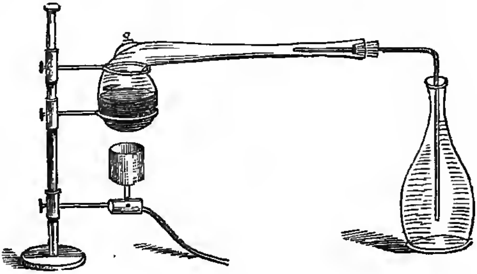


Fig. 50.

483. A candle plunged into a jar of the gas will at once be extinguished. Sulphurous acid, indeed, like carbonic acid, exerts a positively prejudicial influence on combustion. A little infusion of litmus may be poured into a bottle containing it, and the mouth of the bottle closed by the thumb. If the bottle be then briskly shaken for a few minutes, and its mouth afterwards opened whilst under water, the latter will rush up, and nearly or entirely fill the vessel. In this way its action on colouring matter and its solubility in water may be seen at one time.

484. It bleaches vegetable colours, however, as well as changes their tints, and is employed in the arts to bleach wool, silk, straw, sponge, and gelatin. To demonstrate this property, a flower (such as a red rose) may be hung in a vessel of the gas, or suspended over burning sulphur, when its colour will slowly disappear; or an infusion of the purple cabbage to which a little potass has been added, so as to change it to green, may have a current of sulphurous acid sent through it, when it will be observed first to grow red, and then to become colourless.

485. The colour, however, is not completely destroyed, as it is by chlorine; for if the bleached cabbage infusion be divided into two portions, and a little sulphuric acid added to the one, and potass to the other, a red tint will be developed in the former, and a green in the latter. A similar return of colour takes place when flannel is repeatedly washed, when the alkali of the soda and soap causes the reappearance of the original yellow colour of the wool.

486. Sulphurous acid may be employed in the arts for bleaching, either as a gas or in solution in water. A salt containing it, such as the sulphite of soda, Na_2SO_3 [by old notation, NaO,SO_2], and when crystallised, $Na_2SO_3 + 7H_2O$ [by old notation, $NaO,SO_2 + 7HO$], may also be used. This salt has a remarkable power of arresting animal decomposition, and preventing putrefaction. This property commends the acid in the arrestment of the putrefaction of gelatin when used as paper size, and for other purposes where putrefaction is liable to set in.

487. Under pressure and cold, the sulphurous acid becomes a clear colourless liquid, with the specific gravity of 1·380, which boils at 14° F., and at $-105°$ may be obtained in a solid form as transparent colourless crystals.

488. When sulphurous acid combines with a series of bases it forms salts, such as the sulphite of soda, Na_2SO_3, all of which possess more or less strongly the bleaching and antiseptic properties of the gas and of its solution in water. The addition of a stronger acid, such as sulphuric acid, to the sulphite, liberates the sulphurous acid which then acts more powerfully.

Sulphuric Acid or Sulphuric Anhydride.

Combining weight, 80; *symbol*, SO_3.
[*Old combining weight*, 40; *symbol*, SO_3.]

489. Sulphuric acid may be considered the most important of the acids, both on account of its own properties, and because, without it, we should not be able to procure other valuable reagents, such, for example, as nitric, hydrochloric, and acetic acids, carbonate and sulphate of sodium, soap, glass, &c.

490. Sulphuric acid does not occur in nature free, unless in small quantity in the neighbourhood of volcanoes. In a state of combination, as already mentioned, it is found in various minerals. It is prepared for commercial purposes in two ways: 1*st*, by heating green vitriol, the sulphate of iron; 2*d*, by adding oxygen to sulphurous acid, through the medium of hyponitric acid. The variety of sulphuric acid obtained by the first process goes by the name of Nordhausen acid, from the place in Saxony where it is chiefly prepared. It is also called Saxon, or fuming sulphuric acid.

491. Green vitriol consists of sulphuric acid, oxide of iron, and water, its exact composition being $FeSO_4 + 7H_2O$. It is first strongly dried, the effect of which is to expel the greater part of the water it contains. About a seventh part of that, however, is always, and purposely retained. The dried sulphate of iron is then exposed to a red heat in stoneware retorts. Half of the sulphuric acid of the sulphate comes over in combination with water, whilst the other half is decomposed into sulphurous acid, which is evolved as gas, and oxygen, which converts the protoxide of iron into peroxide.

492. Nordhausen acid varies in strength, but when strongest may be regarded as consisting of one combining proportion of water and two of sulphuric acid, $H_2O + 2SO_3$ [by old notation, $HO + 2SO_3$]. It is twice as strong as the strongest English sulphuric acid, or oil of vitriol.

493. It is employed in the arts for dissolving indigo, an acid solution of which is extensively employed in dying blue. It is likewise an object of great interest to the chemist, as it enables him to procure anhydrous sulphuric acid. For this purpose, the strongest Nordhausen acid is gently heated in a retort connected with a receiver kept very cold. The anhydrous acid, or sulphuric anhydride, SO_3, rises in vapour at a temperature of about 80°, and condenses in solid fibres, which are soft, and may be moulded by the fingers like wax. It absorbs moisture from the air—giving rise, in so doing, to the production of dense white fumes. This solid body, which is troublesome to prepare, and is rarely seen, is the only substance properly deserving the title of sulphuric acid; what ordinarily goes by that name being a combination of the solid with water.

494. To prevent confusion, the three most important forms of the acid are thus distinguished:

	Modern Notation.	Old Notation.
Anhydrous sulphuric acid.........	SO_3	SO_3
Nordhausen sulphuric acid........	$H_2O,2SO_3$	$HO,2SO_3$
Oil of vitriol..........................	H_2O,SO_3 or H_2SO_4	HO,SO_3

The last is the one sold in the shops under the name of sulphuric acid, and is the most important of the three. The title oil of vitriol is, in strictness of speech, more applicable to the Nordhausen acid, to which it was originally applied, because that substance is a dense *oily* liquid, obtained by distilling green *vitriol*. The term is now restricted to the English acid.

495. The preparation of the English oil of vitriol is effected in the following way: Sulphur (or pyrites) is kindled in a furnace, and freely supplied with air. It becomes sulphurous acid, which is conducted into a large leaden chamber, along with nitric acid obtained from nitrate of sodium and sulphuric acid and steam. The sulphurous acid takes oxygen from the nitric acid, and becomes sulphuric acid, which combines with the steam, and condenses as a liquid on the floor of the chamber: thus,

$$N_2O_5 + 3SO_2 = 2NO \text{ and } 3SO_3$$
$$[\text{by old notation, } NO_5 + 3SO_3 = NO_2 \text{ and } 3SO_3];$$

or thus:

$$\begin{array}{llllll} \multicolumn{6}{c}{\text{Modern Notation.}} \\ N_2O_5 = & NNOO & O & O & O & \\ 3SO_2 = & & SO_2 & SO_2 & SO_2 & \\ \hline \text{Equal to} & NO,NO, & SO_3, & SO_3, & SO_3 & \end{array} \qquad \left\{\begin{array}{lllll} \multicolumn{5}{c}{\text{Old Notation.}} \\ NO_5 = & NO_2 & O & O & O \\ 3SO_2 = & & SO_2 & SO_2 & SO_2 \\ \hline \text{Equal to} & NO_2, & SO_3, & SO_3, & SO_3 \end{array}\right\}$$

496. The nitric acid, N_2O_5, has three atoms of oxygen removed by the sulphurous acid, and becomes, in consequence, nitric oxide, NO: thus, N_2O_5 *minus* $O_3 = 2NO$. The nitric oxide, NO, produced in this way ascends as gas in the leaden chamber, and combining with oxygen derived from the air filling the space, forms hyponitric acid: thus, NO,NO *plus* $O_2 = N_2O_4$. This hyponitric acid, N_2O_4, like the nitric acid, yields part of its oxygen to sulphurous acid, SO_2, converting it into sulphuric acid, SO_3, and itself reverting to the condition of nitric oxide, NO, which once again acts afresh upon the air, becoming hyponitric acid in the way already described.

497. In this way a small amount of nitric acid suffices to convert a large quantity of sulphurous into sulphuric acid, provided abundance of atmospheric air be also present. It is the air, in truth, which supplies the oxygen requisite for the conversion of the one acid into the other; but sulphurous acid cannot directly take oxygen from atmospheric air, so as to change into sulphuric acid. The nitric acid, accordingly, is essential, playing the part, as it were, of a carrier or go-between, alternately as hyponitric acid, fetching oxygen from the air to the sulphurous acid, and returning as nitric oxide to procure a fresh supply.

498. At intervals the liquid which condenses is drawn off from the floor of the leaden chamber. In this condition, it has the specific gravity 1·600, but is not in a state of sufficient concentration for many purposes. It is deprived, accordingly, of the excess of water it contains, by heating it in shallow leaden troughs, or pans, to a temperature of about 300°, which expels some of the water without dissipating any of the sulphuric acid,

and leaves an acid of specific gravity 1·720. The liquid is further concentrated in vessels of platinum or glass, till it acquires a density of 1·842 to 1·850. It is a definite compound of one combining proportion (80 parts) of acid and one (18 parts) of water, and at 620° to 640° it boils and may be distilled without change. The reader will understand that this compound, H_2O,SO_3 or H_2SO_4, is referred to when we make use of the title oil of vitriol, or *English oil of vitriol.*

499. *Properties.*—Oil of vitriol is a dense, oily, colourless, and odourless liquid. It is highly corrosive, as may be illustrated by letting a drop fall on paper or linen, which is rapidly destroyed by it. This corroding action is accompanied by a blackening or charring of the organic bodies on which it has acted, an effect which is owing to its separating the elements of water from the substance it chars, whilst it rejects the carbon, which appears with its characteristic black colour. This effect may be easily observed by leaving a splinter of wood for a few minutes in oil of vitriol.

500. Sulphuric acid has a strong, sour taste, which can be safely ascertained only with the diluted acid, and it reddens vegetable blues, and changes browns to yellows, like the other strong acids. It is, at ordinary temperatures, the most powerful of these bodies, displacing nearly every one of them from a state of combination. The process for nitric acid was an illustration of the superiority in affinity for the strong bases of sulphuric acid over nitric. It forms an extensive series of salts called the sulphates, many of which are employed in medicine and in the arts and manufactures.

501. The great affinity of sulphuric acid for water has already been referred to. A bottle partially filled with oil of vitriol, if left unstoppered, will by and by run over, in consequence of the increase of volume occasioned by the water which it absorbs from the atmosphere. Advantage is taken of this property to dry substances which cannot be heated without undergoing decomposition.

502. Organic substances—such as sugar or starch—may be

totally deprived of moisture by reducing them to powder, and placing them in shallow saucers above a basin containing oil of vitriol. The whole arrangement is covered by a bell-jar, to exclude the moisture of the outer air. When sulphuric acid combines with water, much heat is evolved, as may be ascertained by quickly mixing four parts of oil of vitriol with one of water in a thin glass flask. The vessel will become too hot to be held in the hand.

503. Sulphuric acid dissolves most of the metals, especially if raised in temperature. The acid first changes the metal into an oxide, and then converts that into a sulphate. When the acid is concentrated, the metal becomes oxidised at the expense of the sulphuric acid, SO_3, which it reduces to sulphurous acid, SO_2. (See par. 478.) This is specially the case with copper and mercury. When the acid is diluted, the metals which dissolve in it derive oxygen from the water associated with it, and hydrogen is evolved, as has already been pointed out when discussing the preparation of that gas. (See par. 270.) Sulphuric acid, whether free or in a state of combination, is readily distinguished by the action of any soluble salt (such as the chloride) of barium, which produces with sulphuric acid a white precipitate of the sulphate of barium, $BaSO_4$, insoluble in water, and in nitric and hydrochloric acids.

504. *Hyposulphurous acid*, S_2O_2, forms with soda, Na_2O, an important compound, hyposulphite of sodium, Na_2O,S_2O_2 or $Na_2S_2O_3$. It may be prepared by digesting sulphur in a solution of sulphite of sodium, Na_2SO_3, which takes up a second atom of sulphur, and on evaporation yields crystals of the hyposulphite of soda, $Na_2S_2O_3 + 5H_2O$ [by old notation, $NaO,S_2O_2 + 5HO$] largely used in photography for dissolving the salts of silver.

Hydrosulphuric Acid or Sulphuretted Hydrogen.

Combining weight, 34; *symbol*, H_2S; *density*, 1·191; ☐☐
[*Old symbol*, HS; *combining weight*, 17].

505. Sulphur forms with hydrogen an interesting and important compound, named hydrosulphuric acid, besides a less

important combination called the persulphide of hydrogen. The former is generally prepared by the action of diluted sulphuric acid on the protosulphide of iron. This sulphide is prepared by heating 4 parts of sulphur, S, and 7 parts of iron, Fe, filings together in a crucible, or by bringing together a stick of roll sulphur and a bar of malleable iron at a white heat. In either case a compound is formed of one atom of sulphur and one of iron, FeS, which, when dissolved in diluted sulphuric acid, yields hydrosulphuric acid.

506. The apparatus employed for the preparation of pure hydrogen is made use of when its compound with sulphur is required. The evolution of the gas depends upon the following change: The sulphide of iron, FeS, decomposes the water, H_2O, of the oil of vitriol, H_2O,SO_3 or H_2SO_4, the sulphur uniting with its hydrogen to form hydrosulphuric acid, H_2S, the iron with its oxygen to form oxide of iron, FeO; which combines with the sulphuric acid, SO_3, forming the sulphate of iron, FeO,SO_3 or $FeSO_4$, green vitriol. Thus in symbols:

$$\text{FoS and } H_2O,SO_3 = H_2S \text{ and } FeO,SO_3 \text{ or } FeSO_4.$$

Or more fully:

First stage of decomposition............$FeS + H_2O = FeO$ and H_2S.
Second stage of decomposition.........$FeO + SO_3 = FeO,SO_3$ or $FeSO_4$.

507. As prepared by the above process, the hydrosulphuric is contaminated with free hydrogen, and where the pure gas is required, the sulphide of antimony, Sb_2S_3, is placed in a retort or flask with bent tube, and is acted on by hydrochloric acid, HCl, and heat applied, when the chloride of antimony is formed, $SbCl_3$, and hydrosulphuric acid is evolved as gas, which may be collected at a stoneware trough (fig. 9).

508. *Properties.*—Hydrosulphuric acid is a colourless gas, having the odour of rotten eggs, which is recognisable when largely mingled with air. 100 cubic inches weigh 38 grains. It does not support combustion, but is itself combustible. It is irrespirable, and a powerful poison, being destructive to the lower animals when diluted with 1000 times its own volume of

air. Water dissolves about two and a half times its volume of the gas, and acquires its offensive odour and taste. The class of mineral waters called sulphureous, such as Harrowgate, contain this gas in solution; only, however, in small quantity.

509. It is a substance of great value to the chemist, as furnishing him with a most useful test for the distinction of metals. The following experiments may be tried with it: A jar of the gas may be kindled, when it will burn with a blue flame, at the same time depositing some sulphur. If mixed with half its volume of oxygen, and kindled, it burns with explosion, its hydrogen becoming converted into water, H_2O, and its sulphur into sulphurous acid, SO_2.

510. Mixed with an equal volume of chlorine, the hydrosulphuric acid is at once decomposed, and its sulphur separates, the chlorine combining with its hydrogen to form hydrochloric acid, HCl. Chlorine may be used in this way to purify apartments contaminated by the gas.

511. A silver coin, or a piece of paper, soaked in a solution of sugar-of-lead, is at once blackened if placed in a jar of hydrosulphuric acid. This effect depends upon the production of a metallic sulphide, by the combination of the sulphur of the hydrosulphuric acid with the silver or lead. This property of the gas causes it to act very injuriously on paintings containing any white-lead, and likewise on silver-plate, and metallic utensils in general. Silversmiths, accordingly, are reluctant to burn coal-gas in their shops, because even the trace of hydrosulphuric acid, which escapes removal during the purification of the former, is sufficient to blacken and tarnish their goods. A white paint having the qualities of white-lead, but which hydrosulphuric acid would not blacken, has long been a desideratum among artists.

512. A solution of hydrosulphuric acid may be prepared by allowing a current of the gas to stream through a jar containing water for a few minutes. If a portion of this be added to a solution of acetate of lead, nitrate of silver, sulphate of copper, and several other metallic salts, it will produce in them black

precipitates, which are sulphides of the metals. A solution of tartar emetic treated in the same way gives an orange precipitate of sulphide of antimony, Sb_2S_3. A solution of arsenious acid, in like manner, gives a bright yellow precipitate of sulphide of arsenic, As_2S_3.

513. A solution of a salt of zinc, such as the sulphate (to which excess of ammonia has been added), and thereafter the hydrosulphuric acid, gives a white precipitate of sulphide of zinc, ZnS. A solution of the chloride of manganese gives a flesh-coloured or pink precipitate of the sulphide, MnS.

514. These experiments illustrate the fact that the majority of metallic sulphides are black; one white, that of zinc; one orange, that of antimony; one flesh-coloured, that of manganese; one yellow, that of arsenic. The sulphide of cadmium is also yellow, and so is the bisulphide of tin.

515. Hydrosulphuric acid, under a pressure of 17 atmospheres, passes into a clear colourless mobile liquid, which can be frozen at the low temperature of $-122°$ F.

516. The persulphide of hydrogen, HS, is prepared by adding persulphide of calcium, CaS_5—obtained by boiling slaked lime, flowers of sulphur, and water together—to dilute hydrochloric acid (one of acid to two of water), when a yellow oil separates, which is the persulphide of hydrogen. The liquid has a density of 1·769, and has bleaching properties.

SELENIUM.

Combining weight, 79; *symbol*, Se; *density in solid state*, 4·3 *to* 4·8; *atomic or combining volume*, 1 *or* □.

[*Old combining weight*, 39·5; *symbol*, Se.]

517. Selenium is a rare substance, closely resembling sulphur in properties, and occurring in nature associated with it. Its name is derived from the Greek Σεληνή (*Selenê*), the moon, in allusion to its similarity in properties to a metallic element, *Tellurium*, which receives its name from the Latin *tellus*, the earth.

518. Selenium is so rare and costly, that the student will not have it in his power to try experiments with it. We mention, therefore, its properties exceedingly briefly. At ordinary temperatures it is a solid, and may be obtained in three different states, as an amorphous powder, a vitreous mass, and as a crystalline body. As generally prepared, it possesses a brownish-red colour, is semi-transparent, and has a lustre somewhat resembling that of the metals. It melts a little above 212°, and boils about 650°, forming a yellow vapour with odour of horse-radish.

519. It combines with oxygen, forming selenic acid, H_2O,SeO_3 or H_2SeO_4 [old notation, HO,SeO_3], which corresponds to sulphuric acid (oil of vitriol), H_2SO_4; and selenious acid, H_2O,SeO_2 or H_2SeO_3 [old notation, HO,SeO_2], analogous to sulphurous acid, H_2,SO_3.

520. It unites with hydrogen to form seleniuretted hydrogen, or hydroselenic acid, H_2Se, a colourless gas obtained by acting upon selenide of potassium or iron by dilute sulphuric or hydrochloric acid. It has a peculiar disagreeable odour, compared to that of decaying horse-radish, the development of which before the blowpipe flame enables us to recognise selenium in bodies containing it. This gas, if respired even in very small quantity, produces excessive irritation of the lining membrane of the nostrils and air-tubes of the lungs, so that it has even been conjectured by an eminent chemist that our epidemic influenza may be occasioned by the evolution of this gas from volcanoes, and its consequent presence in the atmosphere.

521. Selenious acid or anhydride, SeO_2, unlike sulphurous anhydride, is a solid body, easily obtained in crystals by heating selenium in nitric acid.

522. Selenic acid, SeO_3, is procured by fusing selenium with nitre, a process which affords the seleniate of potass, K_2O,SeO_3, or K_2SeO_4. From this the selenic acid is separated by a complicated process. It has never been obtained anhydrous. When most concentrated, it is associated with an atom of water corresponding to oil of vitriol. It is a powerful acid, and has

one property possessed by no other simple acid—that, namely, of dissolving gold. It does not act upon platinum.

523. None of the compounds of selenium, nor the element itself, are used in the arts.

PHOSPHORUS.

Equivalent, 31; *symbol*, P; *specific gravity of solid*, 1·77; *of vapour*, 4·500; *combining measure of latter*, $\frac{1}{2}$ *or* □.

524. *Distribution.*—Phosphorus occurs in the state of phosphoric acid, P_2O_5, in union with bases, chiefly lime and magnesia, in rocks such as apatite and Sombrero guano. It is a never-failing constituent of fertile soils, and of plants used by man and the domesticated animals as food—such as grains, peas, and beans; in which it occurs both in the forms of calcareous phosphates, and in combination with carbon, oxygen, hydrogen, and nitrogen.

525. It is an equally characteristic and important ingredient of animal structures. Their bony skeletons owe their strength and rigidity to the phosphates of calcium and magnesium; whilst phosphorus exists in other states of combination in the flesh, blood, brain, milk, and other tissues and secretions of animals. The remains and excrements of animals, such as coprolites and the various guanos, are rich in phosphates.

526. *Preparation.*—Different processes are followed in the preparation of phosphorus, but the simplest is the following: Bones are burned to whiteness in an open fire, leaving bone ash, principally consisting of tribasic phosphate of calcium, $3CaO,P_2O_5$ or $3Ca,2PO_4$. This ash is ground to powder, and mixed with oil of vitriol somewhat diluted. The whole is well stirred, and left at rest for some hours. At the end of this time fresh-water is added, and the liquid passed through a filter. What filters through is mainly superphosphate of calcium, $CaO,2H_2O,P_2O_5$ or $Ca,H_4,2PO_4$, besides a little sulphate of calcium. There is left on the filter sulphate of calcium, CaO,SO_3 or $CaSO_4$, resulting from the combination of the oil of vitriol with much of the lime of the bones.

527. The impure solution is evaporated to the consistence of a syrup, stirred full of charcoal-powder and fine sand, and heated in an iron vessel till every trace of moisture is expelled. The dried mass is then introduced into a retort made of fire-clay, which is placed in a furnace, and raised to a white heat. From the mouth of the retort a wide copper tube proceeds, which is bent at right angles, and dips below the surface of water contained in a glass vessel.

528. The change that occurs within the white-hot retort is simple. Phosphoric acid, or when uncombined, more strictly phosphoric anhydride, P_2O_5, consists of two combining proportions of phosphorus and five of oxygen. The latter combine with as many atoms of carbon, forming carbonic oxide, which escapes by the bent tube, and bubbles up through the water; whilst the phosphorus, rising in vapour, and descending into the water, condenses there. Thus in symbols:

$$P_2O_5 + 5C = 2P \text{ and } 5CO.$$

529. The phosphorus is melted a second time under the surface of hot water, and run into cylindrical moulds, where it is cooled and solidified in sticks, in which form it is met with in commerce.

530. *Properties.*—Phosphorus is, at ordinary temperatures, a soft, transparent, pale-yellow solid, resembling bees-wax in consistence, and admitting of being cut or moulded like it. It is insoluble in water, under which it is kept, to prevent its spontaneous combustion. It dissolves in the volatile oils, in naphtha, bisulphide of carbon, &c., and may be obtained from these solutions in crystals, which are not, however, easily preserved. It melts at 111·5, and boils at 550°, yielding a vapour which is colourless, and 100 cubic inches of which weigh 135 grains. The volume of the vapour of an atom of phosphorus is only one half that of an atom of hydrogen or oxygen. Ordinary phosphorus slowly begins to rise in vapour a little above the temperature of boiling water.

531. To observe these phenomena, a small piece of carefully

dried phosphorus should be placed at the bottom of a long narrow tube shut at one end. On heating this, the solid will be observed to melt, form an amber-yellow, highly transparent liquid, evolve a pale-yellow vapour, and finally boil. If a wide tube be taken, the phosphorus takes fire, and the phenomena in question are not observed.

532. The most remarkable property of this substance is its excessive inflammability, and the intense light and heat which it evolves when burning. From this character it has received its name from two Greek words, φως, *light*, and φορυς, *beaming*, signifying, in combination, the *light-bringer*, or *light-producer*, being the exact equivalent of the Latin compound *lucifer*. Phosphorus takes fire spontaneously in warm weather, and at all ordinary temperatures is readily kindled by friction, a stroke, or the heat of the hand. It bursts into full flame about 120° F.

533. It is luminous in the dark; as may be observed by placing a stick in a jar of air, or using it, like a crayon, to write or draw with on a wall. In employing it thus, the phosphorus should not be kept long dry, or held in the naked fingers. It may be dipped at intervals into a vessel of water. When phosphorus is thrown into a jar containing hot water, and a stream of oxygen from a gas-holder directed upon it, the phosphorus burns vividly under the surface of the water. A similar combustion occurs when phosphorus and chlorate of potassium are placed in a jar with cold water, and a stream of oil of vitriol from a pipette allowed to flow in.

534. Phosphorus can be obtained in several other forms than that mentioned. The most interesting is red or amorphous phosphorus, which is prepared by heating dry ordinary phosphorus in a flask filled with dry carbonic acid, more strictly called carbonic anhydride, at a temperature of 450° to 460° for several days. It is also formed in small quantity when phosphorus is burned in air or oxygen. A third form of phosphorus is white and opaque, a fourth black and opaque, and a fifth appears in red scales.

535. The various modifications of phosphorus are termed

allotropic, and they afford instances of *allotropy*. Red phosphorus is the same in composition as the common kind, but it differs much in properties. It is a red powder; not liable to take fire, hence not kept under water; not soluble in bisulphide of carbon, &c.; and is not poisonous. At about 500° F., it returns with explosive rapidity to the condition of ordinary yellow phosphorus.

COMPOUNDS OF PHOSPHORUS WITH OXYGEN.

536. Phosphorus and oxygen form four compounds:

	Modern Notation.		Old Notation.
Oxide of Phosphorus……..	P_4O, combining number	140	$P_2O = 70$
Hypophosphorous Acid…	P_2O, " "	78	$PO = 39$
Phosphorous Acid…………	P_2O_3, " "	110	$PO_3 = 55$
Phosphoric Acid (Phosphoric Anhydride)….	P_2O_5, " "	142	$PO_5 = 71$

Oxide of phosphorus is considered to be formed when a stream of oxygen gas is directed against phosphorus fused under hot water. A brick-red powder is produced, but much of this is doubtless *amorphous* phosphorus.

Hypophosphorous Acid.

Anhydrous, P_2O; Hydrated, $HPO = 48$.

[Old notation, Anhydrous, PO; Hydrated, $HO,PO = 96$.]

537. In the preparation of hypophosphorous acid, quick-lime is heated red-hot in a crucible, which is removed from the furnace; and whilst still at a high temperature, pieces of phosphorus are thrown into it. It is then quickly covered by another crucible inverted over it, and heaped up with sand, to exclude air. The phosphorus combines in part with the oxygen of the lime, CaO, to form phosphoric acid, and this with undecomposed lime, to form phosphate of calcium, $3Ca,2PO_4$. At the same time another portion of the phosphorus combines with the calcium of the lime, forming phosphide of calcium, CaP_2.

538. When the contents of the crucible, which are of a dark

brown colour, are thrown into water, the latter is decomposed by the phosphide. Its oxygen combines with the calcium to form lime, and with part of the phosphorus to form hypophosphorous acid, P_2O, which thereafter unites with the lime, forming hypophosphite of calcium, Ca,P_2O. The hydrogen of the decomposed water also unites with the phosphorus, forming phosphuretted hydrogen, PH_3, a gas which, as thus prepared, spontaneously takes fire when it meets air. It is the production of this gas which is the interesting part of the experiment.

539. Every fragment of the phosphide of calcium dropped into the water gives rise to the evolution of bells of phosphuretted hydrogen gas, which rise through the liquid, and burst into flame at its surface, producing beautiful white wreaths of phosphoric acid, and exhaling a strong, offensive, garlic-like odour.

Phosphorous Acid.

Anhydrous, P_2O_3; Hydrated, $H_2PHO_3 = 82$.
[Old notation, Anhydrous, PO_3; Hydrated, $2HO,PHO_4 = 82$.]

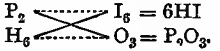
540. Phosphorous acid is the least interesting of the compounds of phosphorus. It may be prepared in two ways. If phosphorus be burned with a limited supply of air, this acid, and not phosphoric, is formed. In illustration of this, a tube of glass should be taken about a foot in length and half an inch in diameter. It is to be bent close to one extremity at an obtuse angle, and the shorter limb drawn out at the blowpipe into a conical shape, so as to leave an aperture not larger than would admit a pin's point.

541. Into the tube, held obliquely with the bent end lowest, and the capillary tube pointing upwards, a small fragment of dry phosphorus is to be introduced, and allowed to slide down into the angle. When the tube is heated at this point, the phosphorus takes fire, and burns with a pale greenish flame; but owing to the small quantity of air which reaches it through the narrow aperture, it forms only phosphorous acid, which is carried along with the heated air, and condenses in the upper

part of the tube as a soft white powder. This is dry phosphorous acid, properly termed phosphorous anhydride, P_2O_3.

542. The second process furnishes the acid in combination with water. When the terchloride, or teriodide of phosphorus, PCl_3, or PI_3, is moistened with water, the latter is decomposed, and its oxygen forms phosphorous acid with the phosphorus. The iodide of phosphorus is prepared by placing a fragment of phosphorus at the bottom of a tube, and covering it with about eleven times its weight of iodine. The two bodies combine energetically together, evolving much heat in so doing. Water is then added. Its hydrogen combines with the iodine, forming hydriodic acid, HI, whilst its oxygen unites with the phosphorus, forming phosphorous acid:

$$2PI_3 + 3H_2O = P_2O_3 \text{ and } 6HI\text{; or thus:}$$



$$\begin{array}{lcl} P_2 & & I_6 = 6HI \\ H_6 & & O_3 = P_2O_3. \end{array}$$

When the aqueous solution is concentrated in a retort, decomposition occurs, and phosphuretted hydrogen is given off.

Phosphoric Acid.

Anhydrous, P_2O_5; Hydrated, $H_3PO_4 = 98$.
[Old notation, Anhydrous, PO_5; Hydrated, $3HO,PO_5 = 98$.]

543. Phosphoric acid, as has been already mentioned, may be procured by the action of sulphuric acid on burned bones. It may also be obtained by the action of nitric acid on phosphorus, which, however, is a troublesome and somewhat dangerous process.

544. It is most conveniently prepared by setting fire to a piece of phosphorus lying on a stoneware plate, or sheet of metal, and covering the combustible, after it is lighted, with a bell-jar (fig. 26). The phosphorus combines with the oxygen of the air to form phosphoric acid, or phosphoric anhydride, P_2O_5, which ascends in the current of hot air as a thick, white smoke, and as the whole cools, falls upon the plate as a soft white solid, scarcely distinguishable from snow in appearance. Oxygen may be taken instead of air, but is not necessary.

Whilst discussing the former gas, we have described the mode in which phosphorus may be burned in it.

545. The snow-like phosphoric anhydride absorbs moisture with great rapidity from the air, and runs into a liquid. When dropped into water, it hisses like red-hot iron quenched in that fluid, owing to the high temperature produced when it combines with it, and then forms hydrated or true phosphoric acid.

546. Phosphoric acid has a pleasant, sour taste, without any flavour. It is not poisonous, nor, speaking generally, corrosive; but from its power to dissolve phosphate of calcium (bone-earth), it acts destructively on the teeth, so that when administered medicinally, it is sucked through a quill or glass tube. It reddens litmus powerfully, and by union with bases, forms a large and remarkable class of salts.

547. Unlike the majority of acids—which combine with bases in the proportion of one combining proportion of the base to one of the acid, so that they are said to be monobasic or single-based—phosphoric acid can in certain circumstances unite with three equivalents of base, with two, or with one. We have thus three modifications of it, which are distinguished by the names monobasic, bibasic, and tribasic, or single-based, double-based, and triple-based phosphoric acid.

Phosphuretted Hydrogen.

Synonyms, 'Will-o'-the-Wisp' and 'Jack-o'-Lantern.' PH_3.
Combining weight, 34; *density,* 1·185; *combining volume,* 2 *or* □□

548. We have already mentioned two processes for phosphuretted hydrogen—namely, the addition of phosphide of calcium to water (par. 538), and the concentration of hydrated phosphorous acid (par. 542). A much more convenient process, however, is to heat phosphorus and sticks of potass along with a little water. The materials are placed in a small stoppered retort, with a long narrow neck (fig. 5). About fifty grains of phosphorus may be taken, as much caustic potass, and no more water than will suffice to cover them.

549. These bodies react on each other nearly in the same way as phosphide of calcium and water. The phosphorus unites with the elements of the water, forming, with its oxygen, hypophosphorous acid, which unites with the potass, and forms hypophosphite of potassium, whilst phosphuretted hydrogen escapes as gas.

550. The beak of the retort must be placed from the first under water, and heat slowly applied. Bells of gas soon begin to ascend through the liquid, and taking fire within the retort, occasion a slight explosion, which is followed by a rushing back of the water along the tube of the retort, to supply the place of the oxygen which combined with the burning gas. It is to prevent accidents during this return of the water that a long tube is prescribed as necessary to the retort. The contraction should not exceed a fifth part of the capacity of the retort; but as the explosion which precedes the contraction is liable to expel some of its gaseous contents, allowance must be made for a greater diminution than that of one-fifth. If the retort be gently heated, the oxygen of the air may be silently consumed, and in any case all danger is over as soon as the oxygen within the generating vessel has been exhausted. The phosphuretted hydrogen then encounters an atmosphere of nitrogen, and cannot burn till it has escaped from the beak of the retort, and risen into the external air.

551. The preparation of phosphuretted hydrogen is one of the most beautiful experiments in chemistry. Each bubble of gas, when it reaches the surface of the water into which the beak of the retort dips, bursts into flame, and changes into a ring or wreath of white smoke, consisting of phosphoric acid mingled with water-vapour. These rings ascend in the air, widening as they rise, and presenting a very curious combination of movements. The whole ring increases in diameter horizontally, whilst it appears to present a series of internal revolutions in a vertical direction, as if made up of a multitude of smaller rings, placed at right angles to the plane or direction of the large one, and each revolving vertically, whilst the great circle

expands horizontally. These circles are produced by the action of the oxygen of the air on the phosphuretted hydrogen, PH_3, with which it combines, converting its hydrogen into water, H_2O, and its phosphorus into phosphoric acid, which, when anhydrous, is P_2O_5.

552. If bells of phosphuretted hydrogen are allowed to ascend into a jar half full of air or oxygen standing on the pneumatic trough, a flash of light is seen within the jar when the gases meet. The experiment is striking, but requires to be cautiously performed when oxygen is employed. Not more than one bell of phosphuretted hydrogen should be allowed to ascend at a time. The jar must be strong and thick, and should be grasped firmly in the hand, to prevent its being thrown over by the concussion which attends the explosive combustion of the gases.

553. At one time there were believed to be two species of phosphuretted hydrogen, differing in composition from each other, and distinguished by the one being spontaneously inflammable in air, and the other not. Hydrated phosphoric acid, when heated, yields the gas in the state in which it is not spontaneously inflammable; as obtained by the other two processes described, it takes fire when it meets the air. No appreciable difference, however, in composition can be detected between the two varieties of phosphuretted hydrogen. Each yields, on analysis, one combining proportion of phosphorus to three of hydrogen.

554. The spontaneously-inflammable variety can be deprived of its characteristic property by confining it over porous charcoal, or mixing it with the vapour of certain combustibles, such as sulphuric ether. The less combustible variety may be rendered spontaneously inflammable by adding to it a trace of nitrous acid. A volatile liquid compound of phosphorus and hydrogen, PH_2, has been ascertained to be present in very small quantity in the more inflammable variety, and absent from the other, and to be the cause of their difference in properties. The vapour of this liquid is spontaneously inflammable.

555. Phosphuretted hydrogen has a strong offensive odour, and is highly poisonous. It is soluble in water, and produces precipitates in metallic solutions. Unlike sulphuretted hydrogen (hydrosulphuric acid), it has no acid properties. Like gaseous ammonia, NH_3, it has the power of combining with hydriodic acid, HI, and forming a salt, PH_4I.

CHLORINE, BROMINE, IODINE, AND FLUORINE.

556. Chlorine, bromine, iodine, and fluorine closely resemble each other in properties, and differ in essential characters from the elements already gone over. Unlike them, they have little affinity for oxygen and a great proneness to unite with hydrogen. Their combinations with the metals—such as chloride of sodium, NaCl, iodide of potassium, KI, and fluoride of calcium, CaF_2—are salts, and resemble in properties the compounds of the oxygen acids with the oxygen bases. From this peculiarity the four bodies we are now to consider are called *simple salt radicals*, because, by union with metals, they produce true salts, as chlorine, by combining with sodium, produces common salt. They are further characterised by forming acids by combination with an equivalent of hydrogen, such as hydrochloric acid, HCl.

CHLORINE.

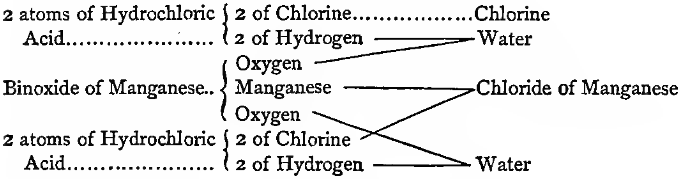
Combining weight, 35·5; *symbol*, Cl; *density*, 2·470;
combining volume, 1 *or* □

557. *Distribution.*—Chlorine exists abundantly in nature, chiefly in combination with sodium, Na, as the chloride of sodium, NaCl, in sea-salt and rock-salt. It occurs in soils and natural waters; and is present in plants and in animals. Its name is derived from the Greek χλωϱος (chloros), yellowish green, in allusion to the peculiar colour of the gas.

558. *Preparation.*—Chlorine is most conveniently prepared by heating in a retort or flask (figs. 5 and 6) the black oxide of manganese, MnO_2, and hydrochloric acid, HCl. A gentle

heat is applied, and the gas comes off rapidly. The change which occurs is the following: Four combining proportions of hydrochloric acid react upon one of the oxide of manganese. In this amount of the acid there are four atoms of hydrogen, and in the oxide two of oxygen. These respectively combine together, forming two atoms of water. There are thus left four atoms of chlorine from the acid, and one of metal from the oxide. The metal combines with two of the atoms of chlorine, forming chloride of manganese, $MnCl_2$, and rejects the other two atoms of chlorine, which come off as gas.

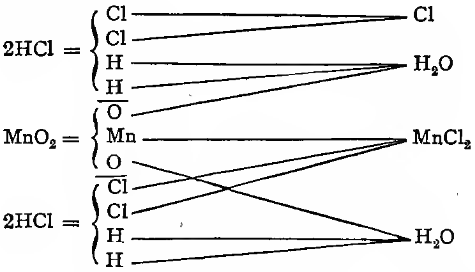
559. The diagram below represents this:



Thus in symbols:

$$4HCl + MnO_2 = 2H_2O, MnCl_2 \text{ and } 2 \text{ of } Cl;$$

560. Or more fully:



561. In consequence of the irritating and suffocating action of chlorine on the lungs, as little of it as possible should be allowed to escape into the room where it is prepared. The jars should be filled with water before the collection of the gas is

commenced; and the latter should be received in jars from the first, without allowing the air in the retort to pass into the apartment.

562. *Properties.*—No gas has more marked properties than chlorine, or admits of a greater number of interesting experiments being performed with it. We shall mention these properties in connection with the experiments which may be tried in illustration of them. Chlorine, as its name implies, has a yellowish-green colour, a colour markedly visible by daylight, especially if a large jar of the gas be placed side by side with one of air in front of a white object, such as a sheet of paper. The peculiar tint of the gas is less distinguishable by artificial light.

563. The odour of chlorine is peculiar. When in small quantity, it is not unpleasant, and resembles that of fresh seaweeds, or what has been called, characteristically enough, the smell of the sea. In larger quantity, the gas excites severe coughing, oppression of the chest, and sometimes even spitting of blood. If breathed undiluted, it produces immediate suffocation. The student, accordingly, must be careful, in uncovering jars of the gas, not to hold the mouth or nostrils directly over them. The irritating effects of chlorine are considerably lessened by inspiring a moderate quantity of the vapour of sulphuric ether, alcohol, or chloroform.

564. When chlorine is prepared over cold water at the trough, a crystalline substance often forms on the sides of the jars in winter, which is a compound of one atom of chlorine and five of water, $Cl + 5H_2O$. When these crystals are placed in a tube, hermetically sealed, and gentle heat applied, two layers of liquid are obtained, the one consisting of *liquid chlorine* and the other of water, holding some chlorine in solution.

565. The density of chlorine, which is nearly two and a half times as heavy as air, is such that it may be collected by displacement in the same way as sulphurous acid (par. 482). One hundred cubic inches weigh 77 to 78 grains. It may be poured from one vessel to another, when its course may be marked by

its colour, or by its action on chemical compounds, such as the nitrate of silver, $AgNO_3$ [old notation, AgO,NO_5], in solution, with which chlorine, like hydrochloric acid, produces a white precipitate, AgCl.

566. Water at 60° dissolves fully twice its volume of the gas, and acquires its odour, taste, colour, and other properties. This solution may be prepared by following the method recommended for procuring that of sulphurous acid (par. 483), and of hydrosulphuric acid (par. 512). This solubility of chlorine makes it advisable to add some warm water to the contents of the pneumatic trough, so as to raise it to the temperature of about 90° before collecting the gas. Chlorine-water, which is a useful reagent, must be kept in the dark. If exposed to direct sunlight, the chlorine combines with the hydrogen of the water, and its oxygen is liberated.

567. The affinity of chlorine for metals may be illustrated by taking antimony reduced to powder, and shaking it into a jar of the gas. The antimony takes fire, and burns brilliantly, combining with the chlorine to form chloride of antimony, $SbCl_3$. In like manner copper and gold-leaf and arsenic introduced into the gas become red-hot, and are converted into their respective chlorides, $CuCl_2$; $AuCl_3$; $AsCl_3$.

568. The characteristic affinity of chlorine for hydrogen may be shewn by mixing the gases in equal volumes. They will not unite in complete darkness; but they combine, with explosion, if exposed to the direct sunbeam, and more slowly in diffuse daylight. It is more convenient, when experimenting, to determine their union by passing an electric spark through the mixture, or applying a light to it. The explosion is more feeble than with oxygen and hydrogen, and the light is faint. The product of combustion is hydrochloric acid, HCl, which will redden infusion of litmus poured into the jar after the explosion.

569. Chlorine cannot support the combustion of such combustibles as burn most brilliantly in air, owing to its indifference to carbon. If a lighted candle, accordingly, be plunged into the gas, it burns with a smoky flame; the chlorine uniting only

with its hydrogen, forming hydrochloric acid, HCl, and rejecting its carbon, which shews itself as soot.

570. The intense affinity of chlorine for hydrogen, and its corresponding indifference to carbon, are still more strikingly illustrated by dipping a piece of thin paper soaked in pure spirits of turpentine, C_5H_8, into the gas. The turpentine bursts into flame, hydrochloric acid is produced, and the jar becomes covered internally with a deposit of carbon.

571. Chlorine unites with olefiant gas, as has been mentioned under that substance. It combines also with carbonic oxide, as may be shewn by mixing the gases in equal measures, and exposing the mixture to sunshine. They rapidly but silently unite, contracting to half their volume. The compound they produce is called chloro-carbonic-acid gas, $COCl_2$, and likewise *phosgene* (more properly, *photogene*)—that is, light-produced *gas*. Its production illustrates the curious power of sunlight in accelerating chemical combination. Phosphorus takes fire in chlorine gas, and forms penta-chloride of phosphorus, PCl_5.

572. The most important of all the properties of chlorine is that of bleaching, by which term is implied a power to destroy all vegetable and animal colours, but not necessarily those of mineral compounds. The destruction of colour is complete and final.

573. Chlorine bleaches only when associated with water. If deprived of moisture, as it may be by transmitting it through bottles containing oil of vitriol, or tubes filled with fragments of chloride of calcium, it will not destroy the tint of a dry colouring matter, provided, at least, sunlight be excluded. In proof of this, a piece of paper stained with infusion of litmus, and thoroughly dried, may be placed at the bottom of a dry glass bottle, which is then to be filled with dried chlorine by displacement. If the bottle be now closed with a stopper, and set aside, the paper will be found to resist the bleaching power of chlorine for days or weeks, even though moisture be not altogether absent. But if a few drops of water are added, the colour will give way in a few minutes.

574. Other experiments may be made in illustration of the bleaching action of chlorine. The gas, or its solution, may be poured into vessels containing infusion of litmus, of purple cabbage, of turmeric, of violets, of indigo, or of any coloured vegetable substance. Ink likewise may be taken, and infusion of cochineal or carmine, to represent an animal colouring matter. The tints of all these bodies will be rapidly and totally destroyed by chlorine.

575. When bleaching is practised on the large scale, a combination of chlorine and lime, called chloride of lime, or bleaching powder, is preferred. This substance is prepared by allowing chlorine to pass into a vessel or chamber containing slaked lime, when the chlorine and lime combine, and form the so-called chloride of lime, $CaCl_2 + CaO,Cl_2O$. The bleaching powder is mixed with water, and the solution filtered or strained. The liquid bleaches very slightly, so that it may be mixed with the solution of any animal or vegetable colouring matter, and the latter will not be destroyed; but if a drop of any of the stronger acids be afterwards added, the colour instantly disappears, owing to the acid combining with the lime, and liberating the chlorine from its state of inactive combination. Cotton is bleached by soaking it first in solution of bleaching powder, and then transferring it to a vessel containing very dilute sulphuric acid.

576. In imitation of this process, a piece of Turkey-red cotton cloth—that is, calico dyed with madder—may be made colourless in a few minutes by soaking it alternately in a saturated solution of bleaching powder and in diluted sulphuric acid. Stains from port wine, fruit-juice, ink, &c., may be readily removed in this way from linen or cotton. The solution of chloride of lime employed for this purpose should be very dilute, and a few drops of vinegar, rather than sulphuric acid, should be added to it after the stained tissue is immersed in the liquid. If bleaching does not speedily occur, a little more chloride of lime and acid may be added; but it is safer to err on the side of too little than too much. The former fault only

protracts the bleaching, and is quite remediable; but if the opposite error be committed, as is too generally the case in domestic bleaching, the excess of chlorine, lime, and acid, which are all powerfully corrosive, totally destroys the fabric.

577. A pretty experiment may be tried with chloride of lime, in imitation of one of the processes employed in calico-printing. A piece of cloth of any colour, provided it owes its tint to an organic colouring matter, such as Turkey-red cotton, is made use of. On this cloth devices are stamped; or where stamps cannot be procured, are painted with a paste consisting of ordinary flour paste, or gum, to which some arsenic, sulphuric, or tartaric acid has been added. The cloth is then dried, and afterwards immersed in a hot solution of chloride of lime. The result of this immersion is to develop the devices *in white* upon a coloured ground, in consequence of the acid of the paste with which they were executed decomposing the chloride of lime, and liberating its chlorine, which destroys the colour of the cloth at all the points impregnated with acid, but does not sensibly affect its tint elsewhere.

578. A property of chlorine not less important than that of bleaching, is the power it possesses of destroying animal effluvia and offensive odours. It is of great service, accordingly, as a disinfectant in fumigating apartments in which noxious animal matters have collected, or persons have resided whilst suffering from infectious diseases. It admits of valuable application also for the purification of the air of sick-chambers whilst occupied by invalids. The chlorine is evolved in the latter circumstances by placing chloride of lime in an open vessel exposed to the air. Chlorine may in this way be set free in sufficient quantity to destroy unpleasant effluvia, without occasioning annoyance to the patient. Where apartments to be fumigated are not inhabited, the chlorine may be evolved from hydrochloric acid and oxide of manganese in the way already described.

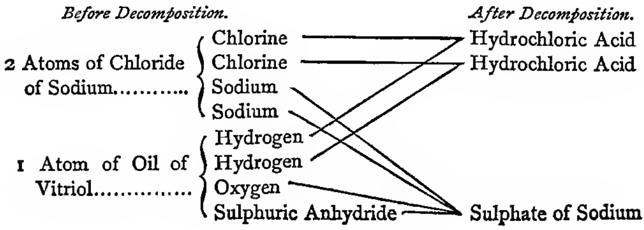
Hydrochloric Acid.

HCl; *synonyms, Spirit of Salt, Marine Acid, Muriatic Acid; combining weight,* 36·5; *specific gravity,* 1·261; *combining volume,* 2 *or* ☐☐.

579. Hydrochloric acid, the most important of all the acids of the simple salt radicals, is prepared in two ways: 1. By the direct combination of chlorine and hydrogen, as mentioned under chlorine; 2. By distilling any metallic chloride with oil of vitriol. Common salt, the chloride of sodium, $NaCl$, is taken for its preparation, on account of its cheapness and purity.

580. In imitation of the process followed on a large scale, the student may place in a retort with receiver (fig. 24) equal weights of common salt and oil of vitriol. The same weight of water is taken, one-third of which is placed in the retort, and the remainder in the receiver. On applying heat, hydrochloric acid is evolved, and condenses in the water of the receiver, whilst sulphate of sodium remains behind. The decomposition is as follows: The sodium of the chloride of sodium, $NaCl$, unites with the oxygen of the water of the oil of vitriol, H_2O,SO_3 or H_2SO_4, to form soda, Na_2O; whilst the chlorine of the salt unites with the hydrogen of the water, and forms hydrochloric acid, HCl, which distils over. The sulphuric acid and soda unite together, and are left behind as the sulphate of sodium, Na_2O,SO_3 or Na_2SO_4.

581. As the preceding is an exceedingly frequent kind of decomposition, with which the student should be well acquainted, we state its rationale still more fully:



Or in symbols:

$$2NaCl \text{ and } H_2SO_4 = 2HCl \text{ and } Na_2SO_4.$$

582. *Properties.*—Hydrochloric acid, as sold in the shops, is a pale yellow or colourless liquid. This is not the true hydrochloric acid, which is a gas, but a solution of it in water; and the yellow colour, when present, is owing to impurity. The strongest commercial liquid acid contains 42 per cent. of real acid, and has a specific gravity of 1·210. Gaseous hydrochloric acid is obtained by pouring undiluted oil of vitriol on perfectly dry common salt, and distilling. It is a colourless invisible gas, forming dense white fumes when it meets moist air, and possessing a pungent, irritating odour. It has a strong, sour taste, and a powerful action on vegetable colours. It liquefies under a pressure of 40 atmospheres. Water dissolves nearly 480 times its volume of the gas, so that it cannot be collected over the water-pneumatic trough. Jars may be filled with it over mercury; but as it is heavier than air in the proportion of 1·261 to 1·000, it may be made to displace air, and so to fill dry vessels. The following experiments may be tried with it:

583. An ounce of the strongest commercial hydrochloric acid is placed in a flask furnished with a tube bent twice at right angles, or a retort with tube (fig. 50). The tube must be long enough to reach to the bottom of the vessels to be filled with the gas. A narrow-necked bottle having been arranged, with the tube descending into it, heat is applied to the flask, and gaseous hydrochloric acid is given off. The bottle may be known to be filled by acid fumes issuing freely from its mouth, when the tube is to be withdrawn, and the mouth of the bottle closed with the thumb. If the bottle be now opened below water coloured blue with litmus, the liquid will rush up with great force, and at the same time become red, so that by the one experiment the great solubility of the gas in water, and its possession of acid properties, may be illustrated.

584. If a candle be plunged into a jar of the gas, it is extinguished without setting fire to the hydrochloric acid, which is neither combustible nor a supporter of combustion.

585. When hydrochloric acid is added to a metallic oxide, it forms a salt with it, but not by simply uniting with the base, as an oxygen acid does. When an atom of dry sulphuric acid or sulphuric anhydride, SO_3, for example, is added to an atom of soda, Na_2O, they simply unite, and form sulphate of sodium, Na_2SO_4. But when hydrochloric acid, HCl, meets an atom of soda, Na_2O, hydrochlorate of soda, Na_2O,HCl, is not produced, but the hydrogen of the acid forms water with the oxygen of the alkali, whilst the chlorine and the sodium combine to form chloride of sodium, $2HCl + Na_2O = H_2O$ and $2NaCl$. This mode of action is exhibited by all the hydracids.

586. The test for hydrochloric acid, whether free or combined, is a soluble salt of silver. The nitrate of silver, $AgNO_3$, is generally taken. It identifies hydrochloric acid by producing in solutions which contain it, or its salts—that is, the chlorides—a white precipitate of the chloride of silver, AgCl, which is distinguished from other similar substances by being perfectly soluble in ammonia, but quite insoluble in nitric acid. The yellow colour of the commercial acid may be due to dissolved organic matter, but more generally to the presence of the chloride of iron. The latter may be indicated by diluting the acid with water, and adding a solution of ferrocyanide of potassium, which gives more or less of a blue colour, according to the quantity of iron.

587. *Aqua regia* is a mixture generally of two parts of hydrochloric acid and one part of nitric acid, and is employed in dissolving gold, platinum, and other substances.

Oxides of Chlorine.

588. There are five oxides of chlorine, which are possessed of some interest. Three of these compounds can be obtained in a separate state.

	Symbols.	Atomic or Combining Proportion.
Hypochlorous Anhydride	Cl_2O	87
Chlorous Anhydride	Cl_2O_3	119
Peroxide of Chlorine	ClO_2	67·5

but four are generally obtained in union with water, thus:

	Symbols.	Atomic or Combining Numbers.
Hypochlorous Acid	$HClO$	52·5
Chlorous Acid	$HClO_2$	68·5
Chloric Acid	$HClO_3$	84·5
Perchloric Acid	$HClO_4$	100·5

589. Hypochlorous anhydride, Cl_2O, is prepared by passing a stream of chlorine through a tube containing powdered red oxide of mercury; and the hypochlorous acid in its hydrated state, $HClO$, is obtained by adding finely powdered red oxide of mercury to a bottle containing chlorine gas and a little water. The bottle is closed with a cork and shaken briskly. The chlorine combines with the mercury to form chloride of mercury, and also with the oxygen to form hypochlorous acid, which dissolves in the water.

590. The solution which is thus obtained of hypochlorous acid possesses powerful bleaching properties, and it is generally considered that bleaching powder owes its properties to the presence of hypochlorous acid. Hypochlorous anhydride, when free, is a gas of a yellow colour, and very unstable. When slightly heated, it explodes, and is resolved into chlorine and oxygen.

591. Chlorous anhydride, Cl_2O_3, is obtained by heating gently in a flask 4 parts of chlorate of potassium, 3 parts of arsenious acid, 4 parts of water, and 12 parts of nitric acid. The two latter should be previously mixed, and the mixture should entirely fill the flask. A greenish-yellow gas, Cl_2O_3 is evolved, which is the chlorous anhydride. It explodes powerfully, and possesses bleaching properties. When brought in contact with water, it dissolves therein, and forms chlorous acid, $HClO_2$.

592. Peroxide of chlorine, otherwise called hypochloric acid, ClO_2, is procured by the action of oil of vitriol on chlorate of potassium, $KClO_3$, a salt already referred to under oxygen. The sulphuric acid combines with the potass, forming sulphate

of potassium, and sets free chloric acid, but this immediately parts with oxygen, and thus becomes changed into peroxide of chlorine, ClO_2. The application of heat, though not essential, accelerates the change.

593. Hypochloric acid, or, as it is also called, peroxide of chlorine, is a yellow gas possessing a peculiar indescribable odour. It is very soluble in water, to which it communicates its colour. It may be collected over mercury, or by the displacement of air. Its most important property is its explosiveness, which is such, that a very slight elevation in temperature suffices to cause its separation into its elements with great violence.

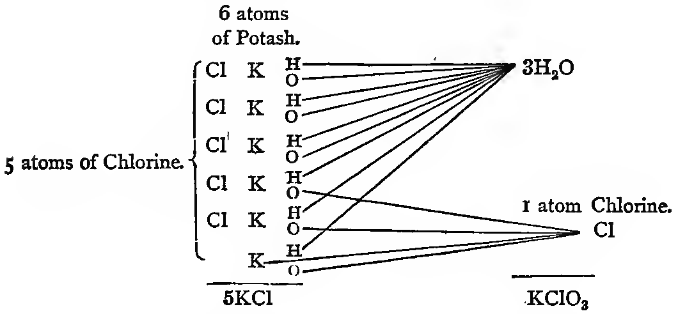
594. To observe this, the experimenter may place in a small test-tube about twenty drops of oil of vitriol, and add to it a grain or two of chlorate of potassium. The tube should be held in a tube-holder, and its mouth turned away from the experimenter. The materials are gently heated, when a yellow gas will fill the tube, and thereafter will detonate sharply.

595. Hypochloric acid supports combustion. A few chips of phosphorus are placed at the bottom of a narrow glass along with some crystals of chlorate of potassium, and the glass is filled nearly to the top with water. Oil of vitriol is then added by means of a funnel, with a tube attached sufficiently long to pass to the bottom of the glass, so that the sulphuric acid may not suffer dilution before it comes in contact with the chlorate of potassium. The heat evolved by the combination of the sulphuric acid with the water and the potass melts the phosphorus, which takes fire in the presence of the hypochloric acid evolved simultaneously and burns with great brilliancy. It is advisable to place the glass on a plate. A mixture of chlorate of potassium and white sugar pulverised separately, at once bursts into flame on the addition of a drop or two of sulphuric acid.

596. Chloric acid, $HClO_3$ [old notation, ClO_5], is not itself a substance of particular interest. Its salts, however, are, and especially the chlorate of potassium. This substance, which, as

well as nitre, is largely consumed in the preparation of lucifer-matches, is prepared by sending a current of chlorine through a solution of potash, KHO. The chlorine combines with the elements of the alkali, forming chloride of potassium with the metal potassium, and with part of the oxygen to form chloric acid, which unites with undecomposed potass to form the chlorate of potassium, $KClO_3$.

597. In this decomposition six atoms of chlorine act on five of potass, forming five atoms of chloride of potassium and one atom of chloric acid, which then unites with a sixth atom of potass, to form chlorate of potassium, $KClO_3$. Thus in symbols:



598. In illustration of this process, the student may send a current of chlorine through a solution of caustic potash till it ceases to turn reddened litmus-paper blue. If the liquid be then gently concentrated by evaporation, it will, on cooling, deposit crystals which are the chlorate of potassium, $KClO_3$. On further concentration, it will deposit a second set of crystals. These are the more soluble chloride of potassium, KCl.

599. The process described is very tedious, and requires a large amount of chlorine. The student may content himself with observing, that when a few drops of a strong solution of potass are added to a bottle filled with chlorine, and the vessel shaken, the yellow colour of the gas disappears in a few seconds, owing to its combination with the elements of the alkali.

600. Hyperchloric, or, as it is also and more generally called, perchloric acid, $HClO_4$ [old notation, ClO_7], is interesting from the large amount of oxygen it contains. When sulphuric acid acts upon chlorate of potassium, as described under hypochloric acid, the oxygen which the evolved chloric acid loses in becoming hypochloric acid does not come off as gas, but combines with undecomposed chlorate of potassium, and converts it into the perchlorate. It may also be prepared by slowly adding crystals of chlorate of potassium into heated nitric acid, when a mixture of nitrate of potassium and perchlorate of potassium, $KClO_4$, is obtained. The latter salt is separated from the nitrate of potassium, which accompanies it, by crystallisation.

601. Perchloric acid may be obtained from the perchlorate of potassium, $KClO_4$, by the action of hydrofluosilicic acid, a substance which will be described under fluorine. Perchloric acid is known only in combination with water. It is the most stable of all the oxides of chlorine, and is characterised by forming with potass a salt very sparingly soluble in water.

602. In addition to the compounds described, chlorine enters into combination with all the other elementary bodies. The chlorides of carbon, boron, and selenium are unimportant, and very difficult of preparation. The chloride of sulphur, SCl, is prepared by passing a current of chlorine over heated sulphur. The two unite to form a dense yellow liquid, having a powerful peculiar odour, somewhat like that of sea-weeds.

603. Fig. 51 shews an arrangement suitable for the preparation of this substance. *a* is a flask containing the materials for chlorine; *b*, a long tube filled with chloride of calcium to dry the chlorine; *c*, a bulb containing sulphur, kept hot by a spirit-lamp; *d*, a bottle kept cold, in which the liquid condenses; *e*, *e*, caoutchouc tubes connecting the glass tubes.

604. There are two chlorides of phosphorus, the one a terchloride, PCl_3, a clear, volatile liquid, obtained by heating together phosphorus and corrosive sublimate; the other the

perchloride or pentachloride, PCl_5, is a snow-white, volatile solid, obtained by introducing phosphorus into dry chlorine, when the former spontaneously inflames, and enters into combination with the gas.

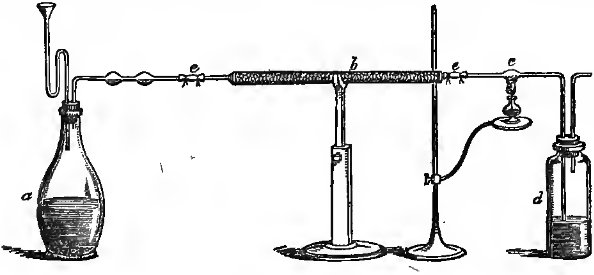


Fig. 51.

605. A more interesting compound than any of these is the terchloride of nitrogen, NCl_3. It is one of the most formidable of explosive compounds, and requires to be prepared with the greatest caution. To procure it, four ounces of pure chloride of ammonium are dissolved in three pounds of distilled water. The solution is placed in a large porcelain basin, having a small leaden saucer lying at the bottom, whilst a two-pound bottle, full of chlorine, is suspended with its mouth downwards, below the surface of the liquid, and directly over the leaden saucer. The liquid rapidly rises within the bottle as it absorbs the chlorine, and drops of a yellow, oily liquid, which are the chloride of nitrogen, collect first on the surface of the liquid, and afterwards sink through the water into the leaden saucer. The bottle must on no account be touched or disturbed whilst the production of the chloride is going on.

606. At the termination of the process, the leaden saucer is cautiously withdrawn, and the chloride may be safely exploded by touching it with a stick dipped in oil. It is immediately resolved into chlorine and nitrogen, with the evolution of heat and light, and the production of a loud noise. It

produces a pit, or indentation, on the leaden saucer. Glass, or even cast-iron, would be shattered to pieces. It is exploded by contact with almost every organic substance containing hydrogen, but especially with oleaginous bodies. The greatest care, accordingly, must be taken to secure the freedom of the vessels used in its preparation from grease, or impurity of any kind.

IODINE.

Combining weight, 127 ; *symbol,* I ; *specific gravity of solid,* 4·947 ; *of vapour,* 8·716 ; *combining measure,* 1 *or* □

607. *Distribution.*—Iodine occurs chiefly in sea-weeds, where it is found in combination with sodium or potassium. It is found in land and water plants and animals, especially those living in marine districts. It is a constituent also of many mineral waters, and a few rare minerals, such as certain ores of silver and zinc.

608. *Preparation.*—Iodine is prepared from kelp, the fused ashes of burned sea-weeds. Kelp is manufactured on the western shores of Scotland and Ireland by burning dried sea-weeds in shallow pits till the greater part of the vegetable matter is consumed. The heat thus produced occasions the fusion of the salts contained in the sea-weed; and when the whole cools, it becomes a solid mass, somewhat like gray trap rock.

609. As the first step towards the production of iodine, the kelp is broken into small pieces, and digested in water. Not more than half of it dissolves in that liquid, the soluble portion consisting of chloride of sodium and of potassium, carbonate of sodium (washing soda), iodide of sodium, and some other less important salts. Of these, the iodide of sodium, NaI, is the most soluble, so that when the solution of kelp is concentrated by evaporation, the chloride of potassium, carbonate of sodium, &c., crystallise out first, whilst the iodide of sodium is retained in solution after the liquid has been reduced to a very small

bulk. This mother-liquor, or iodine ley, is placed in a leaden retort, along with oil of vitriol and black oxide of manganese, and on the application of heat, iodine distils over.

610. In imitation of this process, the student may place in a retort connected with a receiver (fig. 24) a solution of the iodide of potassium, KI, a salt easily procured. Some powdered oxide of manganese is then to be added, and afterwards a little sulphuric acid. When the retort is heated, a beautiful violet vapour will appear, and condense in the neck of the retort and in the receiver in the form of black shining scales.

611. The sulphuric acid acts on the iodide of potassium in a manner analogous to that in which it affected chloride of sodium in the process for hydrochloric acid. As a result, hydriodic acid, HI, is produced, and half of the oxygen in the oxide of manganese combines with the hydrogen of that acid, setting free iodine, whilst the protoxide of manganese left unites with sulphuric acid. There are thus three stages in the decomposition:

$$\begin{array}{lll} (1.) & 2KI + H_2SO_4 & = 2HI \text{ and } K_2SO_4 \\ (2.) & 2HI + MnO_2 & = H_2O, MnO, \text{ and } 2I \\ (3.) & MnO + SO_3 & = MnSO_4 \end{array}$$

612. *Properties.*—Iodine is a bluish-black crystalline solid, with a metallic lustre, greatly resembling plumbago or black-lead in appearance. It is a volatile substance, rising in vapour below 32°, fusing at 225°, and boiling at 347°. It then changes into a very beautiful purple or violet-coloured gas, which is more than eight times heavier than air, and is the heaviest gaseous body. The word iodine is derived from ιώδης (Iodes), violet-coloured, in relation to the appearance of its vapour.

613. Iodine has a peculiar odour, somewhat like that of chlorine, yet sensibly different. It stains the skin brown, but the mark is not permanent. It dissolves to the extent of only one part in 7000 parts of pure water, but if the liquid contain a metallic iodide, such as that of the iodide of potassium, the iodine dissolves in quantity. Alcohol dissolves it readily, and

forms the tincture of iodine. When iron filings are added to iodine in water, the iodide of iron, FeI_2, is formed.

614. Iodine is in small doses a valuable medicine, and in large ones a poison. It stains the skin yellow, which disappears in course of time. It is readily distinguished from all other bodies by its odour, its violet vapour, and its action on a solution of starch.

615. There is no difficulty in observing the odour of iodine. The colour of its vapour is well seen by throwing twenty or thirty grains at once upon a hot brick in the open air. A more economical and convenient method of exhibiting its tint as a gas, is to place a few grains of it at the bottom of a large dry flask, and then to apply heat. The iodine rapidly volatilises, filling the vessel with its vapour, the great density of which is rendered apparent by its dark purple colour at the bottom of the vessel, as contrasted with its rose tint above, and by the sluggishness with which the purple cloud changes its place when the vessel is inclined. At the same time the upper part and sides of the flask become completely covered with dark, black shining crystals of the condensed iodine.

616. A solution of starch is to be prepared as if for use by the laundress, and then cooled. A little of this is to be added to water, and then a few drops of an aqueous or alcoholic solution of iodine. A deep-blue precipitate is immediately produced, consisting of the iodide of starch. If either of the liquids be warm, the blue compound is not produced; or if the liquid be heated after its production, the blue disappears.

617. The experimenter can certify this by pouring boiling water on a small quantity of the blue iodide of starch, when its colour will disappear. A still prettier experiment is to heat some of the blue liquid in a flask. When it has reached the boiling-point, the colour will disappear. If the flask be now suddenly cooled by running cold water on the outside, the blue colour will return. Starch is a test of extreme delicacy for iodine, provided the latter be free; but when its quantity is small, a pale purple or rose tint only is produced.

618. The compounds of iodine very closely resemble those of chlorine, but there are fewer of them. The most interesting one is hydriodic acid, HI, which corresponds to hydrochloric acid. It is obtained in the form of a gas, as was mentioned incidentally under phosphorous acid (see par. 542), by the action of water on the iodide of phosphorus. The hydrogen of the water combines with the iodine to form hydriodic acid, which is a colourless gas, highly soluble in water.

619. Hydriodic acid is procured in a pure state by placing in a narrow tube alternate layers of iodine, then moist powdered glass, a few chips of phosphorus, and more glass, and gently heating the whole mixture. Hydriodic acid is evolved as gas, and may be conducted by a tube into jars, where it will be received by displacement. A solution of the acid is more conveniently prepared by passing a current of hydrosulphuric acid, H_2S, through water, in which iodine, I, is suspended. The hydrogen of the hydrosulphuric acid combines with the iodine to form hydriodic acid, HI, and the sulphur, S, separates. The liquid is warmed and filtered, and furnishes a colourless solution of hydriodic acid, which becomes rapidly brown if exposed to the atmosphere, owing to the combination of the oxygen of the air with the hydrogen of the acid to form water, and the separation of the iodine, which colours the liquid of the brown tint.

620. Hydriodic acid is not a substance of great interest; but its salts (namely, the metallic iodides) are important substances. If hydriodic acid, HI, be added to a metallic oxide, such as potass, KHO, the hydrogen of the acid combines with the hydrated or caustic hydrogen and oxygen of the base to form water, H_2O, and the iodine with the metal, in this case potassium. The resulting salt, the iodide of potassium, KI, is prepared on the large scale by placing iodine and iron in water, when a solution of iodide of iron, FeI_2, is formed, and which is decomposed by the addition of carbonate of potassium, K_2CO_3, forming the carbonate of iron, $FeCO_3$, which is precipitated, and two atoms of the iodide of potassium, KI,

which are left in solution. The latter, on concentration by evaporation and cooling, yield white crystals of iodide of potassium.

Fig. 52.

621. This salt is readily soluble in water, is used in the arts, and is a valuable medicine. An aqueous solution of it supplies the means of readily observing the deportment of a soluble iodide, or salt of hydriodic acid, with reagents, as the following experiments, in test-glasses, will illustrate :

622. To the solution of iodide of potassium, KI, starch is added. No blue colour is produced, for the state of combination in which the iodine is, prevents its combining with the starch. If chlorine gas, however, be now poured from a jar on the surface of the liquid, a blue colour will appear at the upper stratum, and if the contents of the glass be now stirred, they will become uniformly blue. The chlorine, Cl, unites with the potassium, K, of the iodide of potassium, KI, and sets free the iodine, I, which then combines with the starch to form the blue iodide of starch. The blue colour will disappear if too much chlorine be added.

623. To the second glass a few drops of a solution of nitrate of silver, $AgNO_3$, are added. A pale primrose-yellow precipitate is produced of the iodide of silver, AgI, which is insoluble in nitric acid.

624. To the third glass, solution of acetate of lead, $PbC_2H_4O_2$, is added. A bright yellow precipitate appears of the iodide of lead, PbI_2. If this precipitate be boiled with water, it dissolves, forming a colourless solution, from which, as the liquid cools, the iodide separates in brilliant golden crystals. The solubility of the iodide of lead in water may also be observed by adding much cold water.

625. To the fourth glass, solution of corrosive sublimate, or bichloride of mercury, $HgCl_2$, is added. It produces a fine scarlet precipitate of biniodide of mercury, HgI_2. This precipitate is soluble in excess both of the dissolved corrosive sublimate and of the iodide of potassium. If the iodide of mercury,

accordingly, disappears immediately after its production, more of the chloride of mercury is to be added till a permanent precipitate is obtained. When the addition of excess of this salt has dissolved the precipitate, the iodide of potassium will restore it.

626. To the fifth glass, solution of perchloride of platinum, $PtCl_4$, is added. It does not produce a precipitate, but occasions in the liquid a deep red coloration, so that it resembles claret or port wine.

627. By these striking reactions, hydriodic acid and the soluble metallic iodides may always be easily identified, and as iodine is generally found in nature in combination with a metal, they illustrate the mode in which it is generally detected.

628. The first test—namely, starch and chlorine—is the most delicate and generally applicable of the whole. The actions of the other tests may be interfered with, in complex solutions, by the presence of other substances accompanying the iodine.

629. There are two oxides of iodine—iodic acid, HIO_3 [old notation, IO_5], and hyperiodic or periodic acid, HIO_4 [old notation, IO_7]. The last is unimportant.

630. Iodic acid is prepared by heating iodine and nitric acid in a retort together till the iodine disappears. It is partly volatilised, and is lost—partly acquires oxygen from the nitric acid, which it reduces to the state of nitric oxide. The excess of nitric acid is then distilled off, and the liquid cautiously evaporated to dryness. The iodic acid is left as a white crystalline solid, which is anhydrous, readily soluble in water, and then exhibits all the characteristic properties of a strong acid.

631. Iodic acid is a substance of interest, as supplying us with a test for opium, or rather for the active crystalline principle, morphia, which is present in opium. If morphia be added to a solution of iodic acid, it decomposes it, liberating the iodine, which then becomes manifest by the brown colour it communicates to the liquid, as well as by its odour, and the blue precipitate it gives with starch.

632. The teriodide of nitrogen, NI_3, is an explosive substance

like the chloride, but not so formidable, and more easily prepared. It is an insoluble black powder, obtained by digesting together iodine and aqueous ammonia, and then collecting the iodide on a paper filter. The iodide, when dried, explodes with the slightest friction. The filter should be cut when moist into several pieces, each of which may be dried separately.

633. A striking experiment may be performed by transferring a small portion of the moist iodide to a thin china plate, and when it is nearly dry, exploding it by the touch of a hot wire. The iodide blows a hole through the plate at the spot on which it lay, without otherwise injuring it.

634. Iodine and phosphorus combine in several proportions. If a fragment of phosphorus, lying on a metallic plate, be sprinkled with iodine, the substances unite, and heat enough is produced to kindle the phosphorus. The experiment is interesting, as supplying an illustration of what is somewhat rare—namely, the combination of two substances presented to each other in the solid state.

BROMINE.

Combining weight, 80; *symbol*, Br; *density as liquid*, 2·966; *as gas*, 5·540; *combining measure*, 1 *or* □

635. Bromine receives its name from the Greek Βρωμος (Bromos), a disagreeable smell, in allusion to its powerful and offensive odour. It very closely resembles chlorine and iodine in character, and is intermediate in properties between them—excelling iodine in strength of affinity, but being inferior to chlorine. As a mineral, it is a comparatively rare substance. In minute quantity, it occurs in all deposits of common salt, and in some silver ores.

636. *Distribution.*—It occurs in the same circumstances as iodine—namely, in mineral waters, in the sea, and in plants and animals. It is found in these in combination chiefly with magnesium, as the bromide of magnesium, $MgBr_2$.

637. *Preparation.*—On the continent it is prepared from

certain mineral waters rich in it, as from the Kreutznach spring. In this country it is procured from concentrated sea-water. When the latter is boiled down with a view to obtain from it table-salt, the evaporation is never pushed to dryness. Successive quantities of sea-water are concentrated to a small bulk, the crystals of common salt which separate being removed by means of shovels, or colanders pierced with holes. At intervals the residual or mother-liquor is drawn off and set aside. It is a dense oily liquid, containing all the more soluble salts of the sea-water. It is called by the workmen *salt oil,* in allusion to its density, and also *bittern,* in allusion to the unpleasant taste of Epsom salts which it possesses.

638. If the student can procure this bittern, he may prepare bromine from it in the following way: A current of chlorine is sent through the bittern as long as it causes it to darken in colour. The bittern finally acquires a yellowish-red colour. The change in colour is owing to the liberation of bromine, Br, from the bromide of magnesium, $MgBr_2$, present in the bittern. The chlorine combines with the magnesium, forming chloride of magnesium, $MgCl_2$, and the bromine, Br, separating, dissolves in the liquid, and colours it.

639. The liquid is now to be transferred to a retort with a receiver (fig. 24), and heat applied. When it reaches the boiling-point, the bromine passes off as a dark-brown vapour, the colour of which enables its course to be traced along the neck of the retort into the receiver, where it condenses along with water. If the bittern were rich in bromine, the latter will shew itself in dark-brown globules at the bottom of the water.

640. *Properties.*—Bromine is the only element which is liquid at ordinary temperatures, except quicksilver. It is a very dense liquid, having the specific gravity of 2·966 at 60°, which is nearly three times the specific gravity of water, and oil of vitriol floats on its surface. It has a dark brown-red colour, and is opaque when seen by reflected light. When examined by transmitted light, it appears transparent, and the red tint predominates over the brown. Its odour is peculiar, but in small

quantity recalls the smell of the sea, like chlorine and iodine. If cooled down to 9°·5 F., bromine forms a red crystalline solid, somewhat metal like.

641. At ordinary temperatures it is markedly volatile, so that, to prevent its loss by evaporation, it is preserved in tightly-stoppered bottles under the surface of water, or covered by oil of vitriol. It boils at 145°·4, yielding a ruddy-brown vapour, not distinguishable in colour from hyponitric acid, N_2O_4, but quite unlike it in odour. The vapour of bromine extinguishes flame, and is not combustible. Bromine is soluble in water, and more abundantly in alcohol and in ether. When associated with water, it bleaches readily. The taste of bromine is harsh and acrid, and it is a powerful poison. It corrodes the skin, staining it permanently yellow, like nitric acid. With starch, it forms a yellow or pale-orange compound.

642. Bromine has the same strong affinity for the metals and hydrogen which characterises chlorine. Hydrobromic acid, HBr, is obtained as a gas, in imitation of the processes for hydriodic acid, by decomposing bromide of phosphorus by water, and in solution by the action of bromine on hydrosulphuric acid. When it meets metallic oxides, it forms with them water and a metallic bromide. The best known bromide is that of potassium, KBr, a white salt closely resembling the corresponding iodide of potassium, and employed to a small extent in medicine and in the arts. Hydrobromic acid and bromides are readily identified by the fact, that when exposed to chlorine, or heated with sulphuric acid and oxide of manganese, they give off the ruddy-brown vapour of bromine with its characteristic odour.

643. There are several oxides of bromine, of which bromic acid, $HBrO_3$, is the best known. To procure it, bromine is added to the solution of an alkali till it loses alkalinity. On concentrating the liquid, crystals of a bromate first separate and afterwards crystals of a bromide. The change that occurs is closely analogous to that which happens when chlorine acts upon alkalis (par. 597). Bromate of barium, $Ba2BrO_3$, when

decomposed by sulphuric acid, yields bromic acid, $HBrO_3$, a substance closely corresponding in properties to chloric acid.

644. There is a chloride of bromine procured by passing a stream of chlorine through bromine, when a reddish-yellow volatile liquid is formed. A bromide of nitrogen is obtained by acting upon chloride of nitrogen by bromide of potassium.

FLUORINE.

Combining weight, 19; *symbol*, F; *combining volume*, 1 *or* □.

645. *Distribution.*—Fluorine is found in nature pretty widely distributed, but it does not occur anywhere in large quantity. It is never found uncombined, and its most frequent compound is the fluoride of calcium, CaF_2, more familiarly known as fluorspar, from its occurrence in which this element receives its name.

646. Small quantities of fluoride of calcium are found in most fertile soils, and in several natural waters, as well as in the sea. Traces of it, also, are met with in different plants; and it appears nearly constantly to accompany phosphate of calcium in the bones of the higher animals, and likewise in shells and corals. It is especially abundant in certain fossil bones.

647. Fluorine has never been satisfactorily isolated, owing to its great affinity for the metals, and for one of the elements of glass (silicon), so that it cannot be prevented from uniting with these, and eluding our observation. So far as it has been examined, it is said to be a colourless gas, having an odour resembling chlorine, and capable of bleaching. When pure and free it is said not to act upon glass, but it is readily absorbed by potash.

648. Although fluorine itself is so little known, it is otherwise with its compounds, several of which can be easily prepared, and possess striking properties. Of these the most important is hydrofluoric acid, HF. To procure this substance, fluorspar, a

mineral easily procured, is reduced to powder and heated with oil of vitriol. A change occurs exactly analogous to that which leads to the evolution of hydrochloric acid when sulphuric acid acts on a chloride. The calcium of the fluorspar, CaF_2, combines with the oxygen of the water of the oil of vitriol to form lime, CaO, with which the sulphuric acid afterwards unites, producing sulphate of calcium, $CaSO_4$; whilst the hydrogen of the water, uniting with the fluorine of the fluorspar, forms hydrofluoric acid, HF, which is highly volatile, and passes away in vapour. Thus:

$$CaF_2 \text{ and } H_2SO_4 = 2HF \text{ and } CaSO_4.$$

649. In the preparation of this acid, glass vessels cannot be employed. A retort of platinum or of lead, with a receiver of one or other metal, must be made use of. Heat is cautiously applied to the retort, and the receiver is kept very cool by surrounding it with ice. The vapour condenses along with a little water into a fuming volatile liquid.

650. Anhydrous hydrofluoric acid is a colourless gas. It is exceedingly irritating to the lungs, and very corrosive, so that it produces severe sores if allowed to condense on the skin. It may be retained in a bottle made of gutta-percha.

651. Its most interesting property, which leads to its employment in the arts, is that of corroding or etching glass, which it does when strong (but not if anhydrous) with great rapidity. Hydrofluoric acid is employed to act upon glass in two ways. In the one it is intended to etch lines, as of an engraving, or letters, upon a piece of homogeneous glass. In this case the glass is first covered with a layer of bees-wax, or engravers' etching ground (a preparation of asphaltum and turpentine); and the lines or letters are then drawn, or rather, as it were, cut with an etching needle through the covering down to the glass. When the glass is afterwards exposed to the action of the hydrofluoric acid, directed against it in vapour, or poured upon it in the liquid state, it corrodes the glass wherever it is unprotected by the bees-wax or asphaltum. In this way tubes, measures,

and thermometers, may be graduated by the student himself, and the expense of costly pieces of apparatus saved.

652. The other use to which hydrofluoric acid is put, is to produce devices in glass-staining, by a process analogous to that by which white figures are produced on coloured grounds in calico-printing, as described under chloride of lime. The glass to be employed for this purpose consists of two sheets, the one colourless, the other coloured, which have been made to adhere to each other throughout, by heating them in a furnace till they agglutinate, and mutual adhesion takes place.

653. Let the object of the artist, for example, be to produce a white star on a blue ground: a sheet of white glass, plated with one of blue, is taken, and on the latter surface all that is to remain blue is painted over with an asphaltum varnish, whilst the portion which is to appear white (in the case supposed, the star) is left uncovered. A wall of wax is then built round the sheet of glass, and liquid hydrofluoric acid, somewhat diluted, is poured on, and left till it has eaten away the whole thickness of the blue glass, and brought the white into view. By a similar process, but reversing the portions of the glass left uncovered, the star could be obtained blue on a white ground.

654. It is scarcely worth the beginner's while to distil hydrofluoric acid, as nothing can be seen, and moreover, the strong acid is a substance requiring to be handled very cautiously. The power of the acid to etch glass may be sufficiently observed in a simpler way. A small cup, saucer, or porcelain basin, but best of all, a vessel resembling these in shape, made extemporaneously from a piece of sheet-lead, has some powdered fluorspar placed in it, and oil of vitriol poured upon the spar. A square of glass, large enough to cover the basin, is covered with bees-wax, and has a device drawn or written on it with any sharp-pointed body, such as a common pencil, not hard enough to scratch the glass. This is laid with its waxed side downwards, as a cover on the basin, and the latter is gently heated, care being taken that the temperature does not rise so high as to melt the wax. In a few minutes the glass may be

removed, and the wax cleaned from it by means of a little hot turpentine, when it will be found deeply and permanently etched.

655. The test for fluorine in combination is the evolution from its compounds, when heated with oil of vitriol, of an acid vapour (hydrofluoric acid) which etches glass. The student may test for fluorine in this way by heating with sulphuric acid, in a small leaden cup, fragments of a burned bone reduced to powder, under a cover of waxed glass, with a word or device traced on it. The arrangement must be left in a warm place undisturbed for some hours.

656. Fluorine forms no compound with oxygen, being in this respect peculiar among the elements.

657. With silicon fluorine forms a compound of interest, the fluoride of silicon, SiF_4. To prepare it, a mixture of equal parts of powdered glass and fluorspar is placed in a glass flask with oil of vitriol. A dry tube twice bent at right angles, fitting the flask by a cork, is conducted to the bottom of a glass jar, and made to dip below the surface of a small column of mercury. (See fig. 53.) After the tube has been thus arranged, water is poured over the mercury so as to form a column of some inches in height above it, and heat is then applied to the flask. The sulphuric acid, H_2SO_4, and fluorspar, CaF_2, react upon each other, and sulphate of calcium, $CaSO_4$, is formed, whilst hydrofluoric acid, HF, tends to escape as gas. Or in symbols :

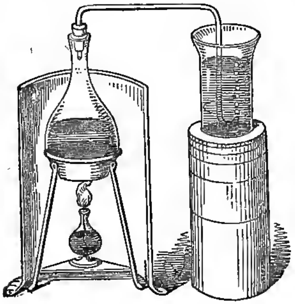
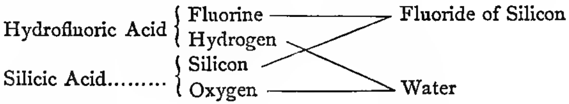


Fig. 53.

$$CaF_2 + H_2SO_4 = CaSO_4 \text{ and } 2HF.$$

658. The hydrofluoric acid immediately reacts upon the silicic acid of the powdered glass, so that the hydrogen of the one

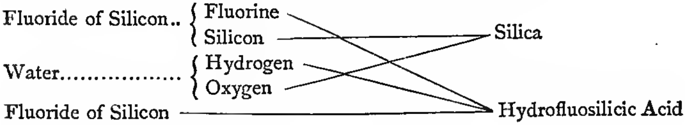
acid combines with the oxygen of the other to form water, and the fluorine of the one with the silicon of the other to form the fluoride of silicon, which is a colourless, invisible gas, as may be observed in the upper part of the flask and bent tube. It is the production of this body that occasions the corrosion of glass when hydrofluoric acid etches it. Thus:



Or in symbols:

$$4HF + SiO_2 = 2H_2O \text{ and } SiF_4.$$

659. When the fluoride of silicon meets water, it decomposes it, the silicon in greater part, taking back oxygen and reproducing silica, whilst the fluorine recovers hydrogen, and becomes hydrofluoric acid. This unites with a portion of the fluoride of silicon which escapes decomposition, forming a compound called hydrofluosilicic, or, more shortly, fluosilicic, acid. Thus:



Or in symbols:

$$3SiF_4 + 2H_2O = SiO_2 + 2(2HF,SiF_4).$$

Hydrofluosilicic acid is separated by filtration from the silica, and is valuable as a test for potass, and for withdrawing it from certain acids. Chloric acid, for example, as well as perchloric, bromic, chromic, &c., are obtained by the action of hydrofluosilicic acid on aqueous solutions of their potass salts.

660. The silica left on the filter is exceedingly pure, and, when dried, presents itself in a state of very fine division.

661. The production of silica in this process allows a very pretty phenomenon to be witnessed. Each bubble of fluoride

of silicon, as soon as it rises out of the mercury into the water, is converted into a little sack or bladder of gelatinous silica. If the bubbles of gas succeed each other very slowly, they produce a tube of silica closely resembling one of animal membrane. The object of the mercury is to prevent the fluoride of silicon meeting moisture till it has issued from the tube. If the latter dipped directly into the water, it would soon become plugged up by the silica produced, and the gas, unable to escape, might burst the flask, and occasion dangerous accidents.

METALLIC ELEMENTS.

GENERAL OBSERVATIONS.

662. The metals are more numerous than the non-metallic elements, there being fifty-two of the former to thirteen of the latter, whilst research holds out the expectation that more will be added to the number. Many of the metals are rare, so that their properties cannot be made matter of general observation; and the more familiar and abundant metals resemble each other very much in properties, so that after the characters of a few of them have been learned, the investigation of the remainder is much less interesting than that of the non-metallic elements. We shall discuss them, accordingly, more briefly than we did the opposite class of simple substances; and with a view to prevent unnecessary repetition, we here give a general preliminary account of their properties.

663. A metal is distinguished from a non-metallic body by three characters, which are presented by it, however, only when it is in mass, and not when it is in the state of a finely-divided powder.

664. These characters are that—1. It reflects light powerfully; 2. Conducts heat excellently; 3. Conducts electricity rapidly. The peculiar brilliancy of polished gold, silver, tin, &c., are

illustrations of the first character. It is distinguished as the *metallic splendour.*

665. The high conductive power of metals is well observed by placing one end of a rod of metal in a fire, when not only does the part which is surrounded by the red-hot fuel become warm, but the heat is conducted, more or less decidedly, to the other parts of the rod which are not in the fire. Metals are the best conductors of heat.

666. They are also the best conductors of electricity. Their employment in lightning-conductors, or thunder-rods, and in the construction of telegraphs, where they convey electricity instantaneously along several hundred miles of wire, sufficiently illustrates this character.

667. Some of the metals, such as gold, occur in nature in small quantity. Others, like iron, are very abundant.

668. A few—such as the metals gold and platinum—occur either uncombined, or associated only with other metals. The great majority, however, are found solely in combination, partly with other metals, but chiefly with non-metallic elements, such as oxygen and sulphur.

669. These native compounds are called the ores of the metals. This term, which is a metallurgical rather than a chemical one, is applied to any native metallic compound which is smelted or otherwise wrought, so as to procure from it the metal it contains. Ores are occasionally alloys, or combinations of different metals; such, for example, are the ores of platinum, in which that metal is associated with palladium, rhodium, iridium, ruthenium, and osmium. More frequently ores are salts, or oxides of the metals. Thus, two of the most valuable ores of iron are oxides, and a third is the carbonate of the protoxide. The most abundant ores of lead, zinc, copper, and antimony are sulphides. Carbonates are pretty frequent; sulphates are less so: but any native metallic compound is an ore which occurs in sufficient quantity to make it worth the metallurgist's while to extract metal from it.

GENERAL PROPERTIES OF THE METALS.

670. The metals are all tasteless when quite pure; even those—such as zinc, copper, and mercury—which, when they enter into combination, produce substances possessing the most strongly-marked taste. The beginner may contrast the tastelessness of silver with the disagreeable taste of one of the compounds of the metal, such as the nitrate in a state of solution.

671. The densities of the metals vary greatly. A few, such as potassium, are lighter than water. One, platinum, is twenty-one times heavier. Lead, which is eleven times denser than water, stands intermediate between the two extremes. The majority of the useful metals are between seven and eight times heavier than water.

672. Considerable diversity of colour prevails among the metals. Four are yellow, gold, calcium, barium, and strontium; and one red, copper. The majority are white mixed with black, giving different shades of gray. In others the white has a shade of blue or red. Thus silver and tin are white. Iron, aluminum, manganese, nickel, cobalt, &c., are gray. Zinc, antimony, potassium, and lead exhibit different shades of whitish-blue or blue-white. Sodium and bismuth have their prevailing white colour modified by red.

673. Till recently, titanium was ranked with copper as a red metal; but the copper-coloured crystals which occur in incrustations in iron blast-furnaces, and which were supposed to be pure titanium, are a compound of this metal with nitrogen. Pure titanium is a gray amorphous powder, which burns with scintillations in ordinary air, and deflagrates brilliantly in oxygen.

674. The colours of metallic compounds are quite different from those of their metals. Thus the salts of the red copper are blue or green; those of iron are not gray, but green or brown; those of lead are almost all white. Those of chromium, which is gray, are green, yellow, orange, &c. No law has

yet been discovered connecting chemical composition with colour.

675. The great majority of the metals are solid at ordinary temperatures. One is a liquid—namely, mercury; and as there is every reason to believe that, if we could condense hydrogen, we should find it presenting all the metallic characters, we may say that one is a gas.

676. The metals which are solid at ordinary temperatures all readily assume regular geometrical forms—that is, occur in crystals; and the majority of them exhibit exactly the same crystalline shapes. The most common of these are the cube (fig. 54) and the regular octohedron (fig. 55). The former is a six-sided solid, with all its faces squares, and all its angles right angles. The octohedron is an eight-sided solid, all the faces of which are equilateral triangles. It resembles in form two pyramids, such as the Egyptian ones, placed base to base. Arsenic, tellurium, and antimony do not crystallise in cubes and octohedrons, but in another shape called the rhombohedron, which has six faces like the cube, but differs from it in its faces not being squares, but rhombic or diamond-shaped, and in its angles not being right angles.

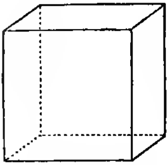


Fig. 54.

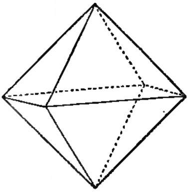


Fig. 55.

677. All the metals are liquid at some temperature, and probably vaporise at very high heats. Their melting-points are very various: thus that of mercury (commonly called its freezing-point) is thirty-nine degrees below zero, whilst that of iron is nearly three thousand times higher; and that of platinum, which is not exactly known, is still more elevated.

678. Certain of the metals—such as potassium, sodium, iron, and platinum—become pasty and adhesive at temperatures much below their melting-points. In virtue of this property,

the first two metals can be moulded like wax at 60°; pieces of iron are welded—that is, compressed into one—at a red heat, and particles of platinum at a white one.

679. A very great difference is observed among the metals in what is called *malleability*—that is, in their susceptibility of being beaten out or rolled into sheets or leaves. The highly-crystalline metals—such as antimony, bismuth, and at ordinary temperatures, zinc—are brittle, and break into fragments when struck with the hammer or passed between rollers. The less crystalline metals, especially those which unite softness with tenacity, exhibit malleability in the highest degree, so that, like gold, they may be beaten into leaves of extreme thinness.

680. These malleable metals admit also in general of being drawn out into wires of great fineness, and are then said to exhibit ductility. Gold is as ductile as it is malleable, but it is otherwise with several of the malleable metals. Iron and platinum are both of them highly ductile; the latter has been obtained, in the form of wire, not more than one thirty-thousandth of an inch in diameter. Neither platinum nor iron, however, admits of being beaten out into very thin leaves. The order of malleability and ductility in metals is gold, silver, copper, tin, platinum, palladium, cadmium, lead, zinc, iron, nickel, potassium, sodium, and solid mercury.

CHEMICAL RELATIONS OF THE METALS.

681. The most general chemical character of the metals is combustibility—that is, readiness to combine with oxygen, with the evolution of light and heat, or at least of heat. The majority of the metals burn readily in air, or failing that, in pure oxygen, as may be seen by heating tin, zinc, antimony, &c., before the common, or, still better, the oxyhydrogen blowpipe, or by exposing them in crucibles to the heat of a furnace or smith's forge. Iron, also, as has been mentioned under oxygen, burns brilliantly in that gas.

682. The rarest and most precious of the metals, as silver, gold, and platinum, are not combustible, but, on the other hand, have their affinity for oxygen lessened by raising their temperature.

683. All the metals, without exception, combine with sulphur, generally in more than one proportion. The same remark applies to chlorine, bromine, iodine, fluorine, and to the other salt-radicals.

684. To avoid repetition under the head of the individual metals, we state here some general facts concerning the mode in which the chief metallic compounds are obtained.

685. *Oxides.*—Many oxides occur native, and in a state of purity. Others are readily obtained by the combustion in air, or oxygen, of their metals.

686. A third and very frequent method is the addition of an alkali, such as potass or soda, to the aqueous solution of a salt of the metal. Thus, to procure oxide of iron, FeO, we add potass to the dissolved sulphate of that oxide, FeO,SO_3 (more strictly, $FeSO_4$). The potass combines with the sulphuric acid, to the exclusion of the oxide of iron, which appears as an insoluble precipitate.

687. A fourth method of procuring metallic oxides is by heating one of their salts containing a volatile acid. Thus, red oxide of mercury, HgO, black oxide of copper, CuO, and oxide of barium, BaO, are obtained by heating their respective nitrates; and oxide of calcium or lime, CaO, is procured by heating its carbonate (limestone or chalk) as in a lime-kiln. In these processes the acid is volatilised by the heat, and the oxide left free.

688. The protoxides of metals are uniformly strong bases, and form, by union with acids, neutral salts. The highest metallic oxides, on the other hand, are acids, and the intermediate oxides are neutral or indifferent. The oxides of manganese supply the best illustration of this, as the following table will shew:

Protoxide of Manganese.......	MnO	Strong base.
Sesquioxide of Manganese.....	Mn_2O_3	Weak base.
Binoxide of Manganese.........	MnO_2	Neutral; neither a base nor an acid.
Manganic Acid....................	MnO_3	Strong Acid.
Hypermanganic Acid..........	Mn_2O_7	Strong Acid.

689. *Sulphides or Sulphurets.*—Many metallic sulphides are found native, as already more than once mentioned.

690. The immense majority of the metals readily unite with sulphur when heated along with it. In this way various sulphides, such as that of iron, FeS, referred to under hydrosulphuric acid (par. 505), are prepared.

691. Hydrosulphuric acid employed alone, or in combination with an alkali, such as ammonia, forming sulphide of ammonium, NH_4HS, converts nearly the whole of the metallic oxides into sulphides; its hydrogen combining with the oxygen of the oxide to form water, and its sulphur with the metal of the oxide to form a metallic sulphide, as illustrated already under hydrosulphuric acid.

692. A few sulphides, scarcely to be prepared in any other way, are procured by heating the sulphate of the metal, whose sulphide is desired, with charcoal, which removes the whole of the oxygen, leaving the sulphur of the sulphuric acid and the metal of the oxide in a state of combination. Thus, sulphate of barium, $BaSO_4$, when heated with charcoal, parts with its four atoms of oxygen which combine with the carbon forming carbonic oxide, CO, which escapes as gas, and leaves behind the sulphide of barium, BaS.

693. The proportions in which a metal combines with oxygen are generally the same as those in which it combines with sulphur; so that if the formulæ of the oxides of a metal are known, those of its sulphides may to a great extent be predicted.

694. *Chlorides.*—Metallic chlorides occur native, as, for example, the most important of all, chloride of sodium or common salt. Many of them may be prepared by bringing the metals and chlorine together, as mentioned under chlorine.

695. A more convenient and generally applicable method is

the addition of hydrochloric acid to the oxide of the metal whose chloride is desired, when, as stated under that acid (par. 585), the hydrogen of the hydrochloric acid combines with the oxygen of the metallic oxide to form water, and the chlorine with the metal to produce its chloride.

696. The carbonate of the metallic oxide is often substituted for the uncombined oxide in the process just described. The carbonic acid escapes with effervescence, and the ultimate product (a chloride) is the same as if the pure oxide had been taken. Similar remarks apply to the production of bromides, iodides, and fluorides.

DIVISIONS OF THE METALS INTO CLASSES.

697. The metals are conveniently divisible into four classes: —1. *Metals of the alkalis*, or alkalifiable metals—that is, metals whose oxides are alkalis. 2. *Metals of the alkaline earths*, or those whose oxides are earthy substances, such as lime, possessed of properties like those of the alkalis, but much less soluble in water than they are. 3. *Metals of the earths proper*, whose oxides are earthy powders, having no alkaline properties, and quite insoluble in water. 4. *Metals proper*—that is, metals with which we are most familiar, in their uncombined or metallic state, which is not the case with the metals of the preceding classes.

698. The metals proper, or familiar metals, are divided into two groups: 1. *Common metals*, such as iron, lead, copper, which are combustible and readily oxidable, and which rust or tarnish in air; 2. *Precious or noble metals*, such as gold, platinum, silver, and mercury, which are not combustible, not readily oxidable, and do not tarnish in air.

METALS OF THE ALKALIS.

699. Five metals belong to this group—potassium, sodium, lithium, cæsium, and rubidium. The latter three are very rare;

but along with potass and soda, ammonia will be considered, as it has all the characters of an alkali, although it is not strictly a metallic oxide.

Potassium.

Synonym, *Kalium; combining proportion*, 39; *symbol*, K.

700. Potassium occurs in nature abundantly, but solely in combination, and chiefly as potass. It is found primarily in granite, trap, and other igneous rocks, associated with different bases in combination with silica. From these rocks, as they crumble down, it finds its way into soils, which are uniformly barren if devoid of potass. Growing plants extract it from the soil; and when they are burned, it forms a chief ingredient of their ashes. It occurs in small quantity also in animals, in natural waters, and in the sea.

701. *Preparation.*—Potassium may be obtained by the action of a voltaic current on potass, but is generally prepared from its oxide, or the carbonate, by complicated processes, which cannot be tried on the small scale. The principle, however, involved in them is simple enough. Carbonate of potassium, K_2CO_3, is heated to a high temperature with charcoal, C, which removes its oxygen, converting it into carbonic oxide, CO, and potassium, K, is liberated. Thus, $K_2CO_3 + 2C = 3CO$ and $2K$. When cream of tartar, which is the acid tartrate of potassium, is heated in a close crucible, it yields *black flux*—an intimate mixture of carbonate of potassium, K_2CO_3, and charcoal, C, and one which is very suitable for the preparation of potassium. Very small fragments of the metal will suffice for the performance of many striking experiments.

702. Potassium has a brilliant white colour with a shade of blue. At the ordinary temperature of the air it is soft like wax, so that it can be readily cut by a knife, or moulded with the fingers. At 32°, it is brittle and crystalline; at 60°, it is soft; at 144°·5, completely liquid, and it may be distilled at a low red heat. It is considerably lighter than water, its density being 0·865, compared with water 1·000.

703. The lustre of potassium disappears instantaneously if it be exposed to the air, owing to its combination with oxygen, and conversion into the white oxide or potass, K_2O.

704. The following experiments may be tried with the metal. If a fragment be heated in a small iron spoon till it begins to rise in vapour, it takes fire, burning with a violet flame. When another minute piece is thrown on the surface of water, it kindles spontaneously, burns with a beautiful purple flame, and combines with the oxygen of the water, as mentioned under hydrogen. If this experiment be made with water coloured by cabbage infusion, the latter will change to green as the potassium burns. When a piece of potassium is laid upon ice, it takes fire as if upon water, melting a hole in it with great rapidity.

705. The great affinity for oxygen, which, as these experiments will illustrate, potassium possesses, makes it necessary to preserve it in bottles filled with naphtha, a liquid compound of carbon and hydrogen, and therefore free from oxygen.

706. *Potass.*—Potass, or the suboxide of potassium, K_2O [old symbol, KO], can be obtained pure only by exposing slices of potassium to dry air, when oxygen combines with it, and converts it into a white, fusible, and volatile solid, having a great affinity for water. If once permitted to unite with the latter, it cannot be deprived of it by any amount of elevation in temperature.

707. Caustic potass or the hydrate of potassium, KHO [old symbol, KO,HO], is a much more important substance than the anhydrous oxide. It is prepared by boiling together a dilute solution of carbonate of potassium, K_2CO_3, and quick-lime, CaO. The lime deprives the carbonate of its carbonic acid, forming with it the insoluble carbonate of calcium, $CaCO_3$, whilst the potass remains in solution in the water as the hydrate of potassium, KHO. The liquid is filtered from the carbonate of calcium and any excess of quick-lime, and forms a colourless solution, to which we shall have constant occasion to refer when treating of the subsequent metals. If this liquid be boiled down, it may be deprived of all the water associated with

the potass, except one proportion, which remains in a state of intimate union with a proportion of the alkali.

708. This compound, the hydrate of potassium, KHO, is raised in temperature till it melts, and then poured into cylindrical iron moulds, in which it consolidates. It is sold in the shops, accordingly, in the form of sticks, under the name of caustic potass, and in solution as *liquor potassæ.* The solid absorbs moisture with great rapidity, and runs into a liquid. In the form of sticks it is employed to withdraw carbonic acid and other gases from gaseous mixtures.

709. Solution of potass is intensely acrid to the taste, and highly caustic, so that it should be tasted only when much diluted. It exhibits the characteristic properties of an alkali in the highest degree. These, it will be remembered, are—1. A peculiar taste; 2. The power of converting vegetable reds into blues or greens, and vegetable yellows into browns; 3. The power of neutralising or destroying the characteristic properties of acids when added in sufficient quantity to them.

710. The further experiment may be tried of exposing some of the potass solution in a shallow vessel to the air, when it will be found after a time to become milder in taste, and to effervesce when mixed with an acid, owing to its having absorbed carbonic acid from the air. To prevent this absorption occurring, solutions of potass should be preserved in stoppered bottles.

711. If the solution of potass be shaken in a bottle with olive or any of the other fixed oils, it will be found to convert it into a soap, illustrating another character of the alkalis.

712. When potassium is heated in dry air, it combines with more atoms of oxygen, forming a chrome-yellow powder, the peroxide of potassium, K_2O_4.

713. *Salts of Potassium.*—Carbonate of potassium, K_2CO_3 [old symbol, KO,CO_2], known in its crude form by the name of potashes, and, when refined, as pearl-ashes, is prepared in large quantities in America and Russia. The ashes of burned wood or grass are lixiviated—that is, placed in large barrels or boxes,

which are then filled up with water. After some time, the water is drawn off from below saturated with soluble matter, and when boiled down to dryness in large iron caldrons, forms the crude potashes, and, when further purified, the pearl-ashes of commerce. Both are impure, from the presence of silicate and sulphate of potassium, chloride of potassium, &c. The pure carbonate is obtained by calcining cream of tartar, digesting the calcined mass in water, and evaporating the filtered liquid to dryness.

714. Carbonic acid is too feeble an acid to neutralise so powerful a base as potass. The carbonate of potassium, accordingly, has an alkaline taste and action upon colouring matter. It also possesses causticity, but these characters are less strongly marked than in uncombined potass. The carbonate is an important salt, being used in medicine, in the manufacture of soft soap, and of glass, as well as in other departments of the useful arts. There is a bicarbonate of potash, $KHCO_3$ [old symbol, $KO,CO_2 + HO,CO_2$], obtained by passing a stream of carbonic acid through carbonate of potassium.

715. *Nitrate of Potassium, Nitre, or Saltpetre,* KNO_3 [old symbol, KO,NO_5].—This valuable salt is brought to this country chiefly from the East Indies, where, as in other warm climates, its formation is constantly going on in the soil. Its employment as a source of nitric acid has been referred to under that substance. It is consumed also to a considerable extent as an antiseptic. Its other great use is as a constituent of gunpowder, of which it forms the chief part by weight, the other ingredients being charcoal and sulphur. These substances are mixed very nearly in the proportion of one combining proportion of nitre, one of sulphur, and three of carbon.

716. When gunpowder is kindled, the oxygen of the nitre combines with the carbon, forming carbonic oxide, or carbonic acid, whilst the sulphur unites with the potassium of the nitre, and the nitrogen is set free. The amount of gas thus produced occupies a space 400 times greater at the ordinary temperature than the gunpowder which evolves it does before being fired.

But the heat produced by the combustion triples at least the volume of the gases (carbonic acid or oxide, and nitrogen). It is this rapid expansion of gunpowder to a bulk some 2000 times greater than it possessed before being kindled, which confers on it its greater propulsive and disruptive powers.

717. Sulphate of potassium, K_2SO_4 [old symbol, KO,SO_3], and bisulphate of potassium, $KHSO_4$ [old symbol, $KO,SO_3 + HO,SO_3$], are used in the arts, the former in medicine, the latter in calico-printing.

718. The chlorate of potassium, $KClO_3$ [old symbol, KO,ClO_5], and the hyperchlorate, $KClO_4$ [old symbol, KO,ClO_7], have been referred to under their respective acids. (See pars. 596 and 600.)

719. *Sulphides of Potassium.*—The subsulphide, K_2S [protosulphide, KS], is obtained by heating the sulphate of potassium with charcoal. It forms a crystalline mass, soluble in water, and possessing a caustic, bitter, sulphureous taste. By fusing the carbonate of potassium with sulphur, protosulphide, KS [bisulphide, KS_2], and a sesquisulphide, K_2S_3 [tersulphide, KS_3], may be obtained. A higher sulphide, K_2S_5 [pentasulphide, KS_5], is also known.

720. *Chloride of Potassium*, KCl, is procured in the process for chlorate of potassium, as mentioned under chloric acid. It is also left as the residue when chlorate of potassium is heated till it parts with all its oxygen, as stated under that gas. It is likewise one of the constituents of kelp, referred to under iodine, and is extensively extracted therefrom.

721. Chloride of potassium closely resembles common salt in appearance, and is employed in the manufacture of the important substance alum, and in the conversion of nitrate of sodium into nitrate of potassium.

722. *Iodide of Potassium*, KI, and *Bromide of Potassium*, KBr, are of more interest as preparations of iodine and bromine than as salts of potassium. These salts have already been noticed under hydriodic acid (par. 620) and hydrobromic acid (par. 642).

723. *Tests for Potassium.*—A salt of potassium—that is, such a body as chloride of potassium, or nitrate of potassium—is distinguished from all bodies, but compounds of the other alkalifiable metals, or of ammonia, by the two following characters, which the student can observe, with a solution of any pure salt of potassium, such as nitrate of potassium or nitre.

Fig. 56.

To one portion of the solution contained in a wine or test glass (see fig. 56) solution of sulphide of ammonium, NH_4HS, is added, which will occasion no precipitate, because the sulphide of potassium is soluble. To another portion in a second glass, solution of phosphate of sodium and ammonia are added. These also will occasion no precipitate.

724. These results prove that either a compound of potassium, sodium, or ammonium may be present, but the choice is limited to one of these three (the rare metals, lithium, cæsium, and rubidium being excluded), for the salts of all the other metals precipitate one or both of these reagents.

725. That it is potassium which is the metal present, is ascertained by the following tests. To one portion of the solution, tartaric acid dissolved in water is added, and the whole stirred well. It will produce a white crystalline precipitate, consisting of the acid tartrate of potassium (cream of tartar), a combination of tartaric acid, potass, and water.

726. To a second portion of the solution of the salt of potassium, solution of the perchloride of platinum, $PtCl_4$, is added. It will produce a yellow crystalline precipitate of the chloride of platinum and potassium, $2KCl + PtCl_4$.

727. A third portion of the original solution is evaporated to dryness, or, to save this trouble, a portion of the dry salt with which the solution was made is taken and moistened with alcohol, which is then set fire to. It will burn with a faint violet flame, such as potassium itself exhibits when kindled.

728. The same phenomenon will take place if the potassium salt, held in a loop of platinum wire, be heated in the inner or reducing flame of the blowpipe. The violet flame is more

distinctly seen when the operator looks through a piece of cobalt blue glass.

729. It may be observed to great advantage by throwing a handful of nitre into an open fire, when a magnificent purple flame is exhibited, owing, as in the alcohol and blowpipe experiments, to the separation of the potassium in the metallic state and its subsequent combustion.

730. We have gone over the tests for potassium in combination more fully than we shall discuss those of most of the subsequent metals, as it is the first under notice. The beginner should be exercised in the application of the tests by having a salt given him of one of the alkalis, with instructions to ascertain whether it be a compound of potassium or not, and so also with the other metals.

Sodium.

Synonym, *Natrium*; *combining proportion*, 23; *symbol*, Na.

731. *Distribution.*—Sodium occurs in nature abundantly in combination, but nowhere free. Its most important native compound is its chloride, which, as rock salt, occurs in immense beds in the solid crust of the earth, and in solution in probably every natural water, as well as in the sea.

732. Compounds of sodium occur in many minerals and in most soils. They are found in small quantity in the majority of land plants, but largely, as kelp illustrates, in those of the sea. Sodium also occurs abundantly as common salt in the structures of the higher animals.

733. *Preparation.*—Sodium is prepared on the large scale from dry carbonate of sodium, 717 parts, powdered charcoal, 175, and finely powdered chalk, 108. The whole is kneaded into an intimate mixture or paste with oil, and distilled in an iron retort, when the metal sodium passes over in vapour, and is received in naphtha. It is more easily obtained than the metal potassium, and is consequently much cheaper.

734. *Properties.*—Sodium has a bright lustre and a white

colour, with a shade of red. It is soft, and readily moulded at 60°, melts at 207°·7, and rises in vapour at a red heat. It is lighter than water, its specific gravity being 0·972.

735. The following experiments may be tried with it: Thin slices exposed to the air will be found to tarnish and grow dim rapidly; and finally, to become converted into a soft, white substance, which is anhydrous soda, Na_2O. A fragment heated in a spoon burns with a yellow flame.

736. An irregular fragment of sodium thrown upon the surface of cold water will rapidly assume a globular form, and roll along the surface with great rapidity, decomposing the water as potassium does, but unlike it, not catching fire. If this experiment be repeated with hot water, with ice, or snow, or if the sodium be laid on a piece of metal, and a drop or two of water allowed to fall on it, it will kindle, and burn with its rich yellow colour.

737. When infusion of purple cabbage is substituted for pure water, it will be coloured green by the soda produced.

738. *Soda.*—Soda, Na_2O, is obtained anhydrous by the exposure of sodium to the air, as already mentioned. Its hydrate, $NaHO$ [old symbol, NaO,HO], is obtained in solution by boiling lime with carbonate of sodium, Na_2CO_3, dissolved in water. When the liquid thus procured is evaporated to dryness, it leaves a solid residue of the hydrate of sodium or soda, $NaHO$, which is fusible, highly soluble in water, caustic, powerfully alkaline, and closely analogous to hydrate of potassium or potash in all its properties.

739. *Compounds of Sodium.*—Nitrate of sodium, $NaNO_3$ [old symbol, NaO,NO_5], otherwise known as cubical nitre or Chili saltpetre, occurs abundantly in Peru, where it is found covering the soil in many districts. It deliquesces in damp air, and burns much more slowly with combustibles than the nitrate of potassium. These properties make it unsuitable for the manufacture of gunpowder; but it is largely consumed as a source of nitric acid, and is employed in agriculture as a fertiliser. It is also used for the manufacture of nitrate of

potassium, by heating the nitrate of sodium, $NaNO_3$, with the chloride of potassium, KCl.

740. Sulphate of Sodium, *Glauber's Salt*, $Na_2SO_4 + 10H_2O$ [old symbol, $NaO,SO_3 + 10HO$].—This salt is manufactured in large quantities by the action of oil of vitriol on common salt, and is the residue of the process for hydrochloric acid, as mentioned under that substance.

741. Glauber's salt is used to some extent in medicine, but is chiefly manufactured with a view to its conversion into carbonate of sodium.

742. Carbonate of Sodium, $Na_2CO_3 + 10H_2O$ [old symbol, $NaO,CO_2 + 10HO$], is one of the most important chemical substances, from its consumption in bleaching, glass-making, soap-making, washing, baking, medicine, &c. It is obtained from different sources:

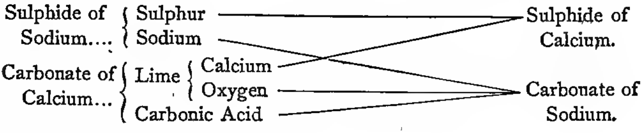
743. One source is kelp, which contains from 2 to 5 per cent. of the carbonate of sodium. A second is barilla—the saline ash left after the combustion of certain maritime, not marine, plants (*Salsola soda* and *Salicornia herbacea*), which are cultivated on the shores of the Levant for the sake of the soda they contain. Barilla contains about 18 per cent. of the carbonate.

744. Another source is the native carbonate (frequently a sesquicarbonate), found on the margins of certain bodies of water in Egypt and other parts of Africa, as well as in Mexico and in Hungary. The Egyptian lakes which are the most familiar are called the 'Natron Lakes,' and have yielded soda from a very remote period. The nitre of the Bible, which is referred to as having detergent properties, is this natron, or carbonate of sodium; not our nitre, the nitrate of potassium.

745. The greater part, however, of the carbonate of sodium used in Great Britain is manufactured from sulphate of sodium, which in its turn, as already mentioned, is procured from common salt by heating it with oil of vitriol.

746. The sulphate of sodium, Na_2SO_4, in the anhydrous state, is reduced to coarse powder, and heated in a furnace with ground coal, which removes from it all its oxygen, and reduces

it to sulphide of sodium, NaS, and with chalk—carbonate of calcium, $CaCO_3$—when the sulphur unites with the calcium of the carbonate, and the sodium with its oxygen and carbonic acid, thus:



In symbols:

$$Na_2S \text{ and } CaCO_3 = Na_2CO_3 \text{ and } CaS.$$

747. We have given only an outline of this process. The product is dissolved in hot water, and yields, on evaporation, crystals of the carbonate of sodium, which contain ten atoms of water. It is readily soluble in water, and has an alkaline taste and action on vegetable colours. The sulphide of calcium is left as an insoluble oxysulphide.

748. Bicarbonate of Sodium, $NaHCO_3$ [old symbol, $NaO,CO_2 + HOCO_2$], is prepared by passing carbonic acid over the carbonate. It has a mild taste and a feeble alkaline action. It is used in the preparation of effervescing powders, and as a baking powder.

749. Phosphate of Sodium, $Na_2H,PO_4 + 12H_2O$ [old symbol, $2NaO,HO,PO_5 + 24HO$], is useful as a test and in medicine.

750. SULPHIDE OF SODIUM, Na_2S [old symbol, NaS], which has been referred to already, as prepared from the sulphate of sodium by withdrawing its oxygen, as a step in the soda process, is also important as one of the ingredients of *lapis lazuli*, from which *ultramarine* is prepared. An artificial ultramarine, rivalling the native pigment in beauty, is obtained by heating sulphide of sodium with silica, alumina, and iron. The other sulphides of sodium, which resemble those of potassium, are not important.

751. The chloride of sodium, or common salt, NaCl, has been noticed under chlorine (par. 557). The bromide, NaBr, is unimportant. The iodide, NaI, resembles the corresponding

salt of potassium. It occurs in kelp, and is interesting as the source of iodine, under which it has been noticed (par. 609).

752. *Tests for Sodium in combination.*—A strong solution of common salt, or of carbonate of sodium, is to be prepared, and five test-glasses half filled with it. To the first, solution of sulphide of ammonium is added. It will occasion no precipitate. To the second, solution of phosphate of sodium and ammonia. They will also occasion no precipitate.

753. These negative indications only go the length of proving that the salt tested may be a compound of potassium, or sodium, or ammonium. To the third glass, solution of tartaric acid is added, and the whole stirred, but no precipitate is given; whilst to the fourth, solution of bichloride of platinum is employed and no precipitate is yielded. The non-appearance of precipitates with the last two tests proves the salt *not* to be one of potassium.

754. To the fifth glass, quick-lime or caustic potash is added. No odour of spirits of hartshorn is emitted. The absence of odour proves the salt *not* to be one of ammonium, as will be explained more fully under that substance. And as it has already been shewn not to be a salt of potassium, it must be one of sodium; for the first two tests tried, limited us to sodium, potassium, or ammonium; and the three following tests have rejected the last two bodies, so that we are limited to the first.

755. The solution may now be evaporated to dryness, and its residue examined as to the test it communicates to flame. To avoid this trouble, dry common salt may be taken and heated at the blowpipe, or moistened with alcohol, and the latter set fire to. In either case the same bright yellow flame which characterised burning sodium will be observed.

756. The flame test is seen to greatest advantage by throwing a handful of nitrate of sodium on a cinder-fire; but in all circumstances it is readily noticed, and is greatly more distinct on the small scale than the violet flame of the potassium salts; so that, if one of the latter be mixed with a compound of

sodium, and the effect of the mixture on flame observed, the yellow light will be found completely to overpower the violet. This, accordingly, is a delicate and convenient test for dry salts of sodium. There is no suitable *positive* test for them in solution, but they are easily detected by the negative method explained.

AMMONIUM AND OTHER COMPOUNDS OF HYDROGEN AND NITROGEN.

Ammonium.

Combining proportion, 18; *symbol*, NH_4; *hypothetical*.

757. Every attempt to isolate the hypothetical metal ammonium has failed. Its oxide is well known, being ammonia or hartshorn. It receives its name from the substance which yields it most readily—namely, chloride of ammonium (sal-ammoniac). This was called by the Romans *Sal Ammoniacum*, or the Ammonian salt, from Ammonia, a district in Libya which supplied it, where Jupiter Ammon, or rather a corresponding Egyptian god, Amun, was worshipped. It was called by the alchemists spirit of hartshorn, because they obtained it by the distillation, in close vessels, of deers' horns. Ammonia is also called the volatile alkali. All those names are still in use.

758. When coals are distilled, as mentioned under coal-gas, much ammonia is produced from the combination of the nitrogen and hydrogen of the coal. When bones are similarly treated in the manufacture of bone-charcoal, the same substance results; in both cases, however, in a state of great impurity. The gas or bone-liquor is mixed with hydrochloric acid, which expels carbonic acid and hydrosulphuric acid, previously in union with the alkali, and combines with the ammonia, forming the chloride of ammonium (sal-ammoniac), NH_4Cl. This salt is purified by repeated solution, crystallisation, and sublimation, and is then ready to yield ammonia.

759. The sal-ammoniac is reduced to powder, mixed with slaked quick-lime, and heated in a retort, or flask with a bent tube. Ammonia, in the state of gas, is evolved abundantly; and being very soluble in water, must be collected at the mercurial pneumatic trough, or by displacement of air. As it is only about half as heavy as the latter, jars or bottles to be filled with it must be held above the vessel from which it is issuing, not below, as was the case with sulphurous acid and chlorine. (See fig. 57.)

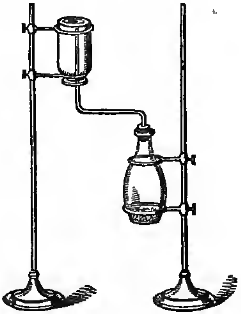
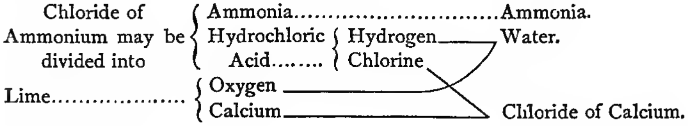


Fig. 57.

760. The following diagram will explain the decomposition that leads to the evolution of anhydrous gaseous ammonia, NH_3:



Or in symbols:

$$2NH_4Cl \text{ and } CaO = 2NH_3 + H_2O \text{ and } CaCl_2.$$

761. A number of interesting experiments may be tried with this important and curious gas, in illustration of its chief properties: Its odour is familiar to all as that of smelling-salts, or spirits of hartshorn. It is best observed by contrasting the absence of odour which characterises sal-ammoniac, with the immediate development of the hartshorn-smell which attends the addition to it of moist quick-lime or potass. Its harsh alkaline taste must be tried with a dilute solution of the gas.

762. The ammonia possesses an alkaline action on colouring matter, which is observed when pieces of paper stained with turmeric, rhubarb, reddened litmus, or the purple cabbage, are

exposed to the gas. The first two become brown, the third blue, and the fourth green. The same effects are produced by sending a current of the gas through infusions of these colouring matters.

763. Water can dissolve about 500 times its volume of ammoniacal gas. To illustrate this, a bottle is filled by displacement with the gas, which is evolved most quickly by boiling in a flask with a long upright tube (see fig. 57) a small quantity of the strong aqueous solution of ammonia sold by apothecaries under the title of *aqua ammoniæ fortissima* (strongest ammonia-water). The bottle, after being filled, is closed with the thumb, and opened under the surface of water coloured with the infusion of cabbage. The water rushes up with great violence, changing its tint as it ascends from purple to green.

764. When ammonia encounters any of the volatile acids, white fumes are produced. These may be readily observed by rinsing a bottle with hydrochloric acid, and inverting it over a bottle containing a little of the strongest ammonia-water. The fumes are occasioned by the combination of the acid and volatile alkali to form sal-ammoniac, NH_4Cl.

765. Ammonia forms a splendid azure-blue compound with salts of copper. To produce it, a small quantity of solution of sulphate of copper is added to a glass of water, and a stream of gaseous ammonia sent through it, or ammonia-water is added drop by drop. In either case, the first effect of the addition of the ammonia is to produce a greenish-blue precipitate; but when more ammonia is supplied, this is redissolved, and an azure solution produced.

766. By any of the foregoing characters, ammonia, when uncombined, may be recognised, but the most readily observed and the most delicate are its odour, and its action as a gas on colouring matter, both of which are eminently distinctive.

767. Ammonia, in association with water, rivals, in all their properties, the fixed alkalis, potass and soda. Like them, it unites with acids, and forms salts. When the gaseous ammonia combines with the acids, there is always one atom, at

least, of water present for two atoms of gaseous ammonia; and this water is essential, for if we attempt to withdraw it, the salt suffers destruction. A striking example of this is furnished by the process for nitrous oxide, where the expulsion of the atoms of water from nitrate of ammonium determines the resolution of that salt into water and nitrous oxide, as detailed under that gas. (See par. 338.)

768. The most important compounds of ammonia with the acids are the nitrate, the carbonate, the sulphate, and the chloride.

769. *Nitrate of Ammonium*, NH_4NO_3 [old symbol, NH_4O,NO_5], has already been sufficiently referred to under nitrous oxide (pars. 338 and 339).

770. *Carbonate of Ammonium.*—Ammonia and carbonic acid combine, along with water, in a great number of proportions. The carbonate sold in the shops is in general a sesquicarbonate; or for each atom of hydrated ammonia, there are an atom and a half of carbonic acid. In stating the composition of such a salt in numbers, the proportions are doubled, so as to avoid the notation of half an atom, thus: $2(2NH_4,CO_3)CO_2$ [old symbol, $2NH_4O,3CO_2$].

771. This salt is prepared by heating a mixture of powdered sal-ammoniac, NH_4Cl, and chalk, $CaCO_3$, when the ammonia of the one compound, uniting with the carbonic acid of the other, as well as with water produced during the process, exactly in the same way as in the process for pure ammonia, sublimes as a volatile salt, which condenses in crystals in the upper part of the subliming vessel. On the small scale, a flask may be used; on the large, an egg-shaped pot of iron is employed.

772. Carbonate of ammonium has an odour scarcely distinguishable from that of the free alkali. It is the smelling-salts of the shops, which are best made by mixing in a bottle coarsely-powdered sal-ammoniac and carbonate of potassium. The reaction of these on each other leads to a constant evolution of the volatile carbonate, which may be increased at intervals by stirring the mixture, and putting the bottle in a warm place,

with the occasional addition of a drop of water, if the contents appear too dry.

773. The carbonate is one of the most important salts of ammonia. In addition to its direct employment in the arts and in medicine, it is valuable as enabling us to prepare all the salts of ammonia by neutralising it with the acid whose salt is desired. Thus the nitrate is procured by adding the carbonate to nitric acid; and the acetate and citrate, which are used in medicine, by neutralising the carbonate with acetic acid (vinegar) and citric acid (lime juice).

774. *Sulphate of Ammonium*, $2NH_4,SO_4$ [old symbol, NH_4O,SO_3]. —This salt is now a considerable article of commerce as a fertiliser. It is prepared on the large scale, by neutralising the gas liquor or bone liquor, as well as other liquids containing ammonia, with oil of vitriol, and purifying by crystallisation.

775. *Chloride of Ammonium.*—When ammonia, or its carbonate, is neutralised by hydrochloric acid, the resulting combination is chloride of ammonium or sal-ammoniac, contains dry hydrochloric acid united to dry ammonia, and possesses the symbol NH_4Cl. The iodide, bromide, fluoride, and sulphide of ammonium, NH_4I; NH_4Br; NH_4F; NH_4HS; are all in like manner anhydrous. Of these salts, the first and last only are important.

776. Sal-ammoniac has been already sufficiently referred to as regards its source, its mode of preparation, and its employment to yield pure ammonia and its carbonate. It is sold in the shops in large, hollow, hemispherical cakes, which owe their shape to the leaden domes or cupola-like covers of the iron pots in which the salt is sublimed. It has in cake a peculiar tough and fibrous structure, which makes it one of the most difficult substances to pulverise. When struck with the pestle, it splits into threads without crumbling into powder. It may be obtained in regular crystals, both by sublimation and by evaporation of its aqueous solution. Their shape is the same as that characteristic of the majority of the metals—namely, the cube and octohedron.

777. *Sulphide of Ammonium*, NH_4HS, is prepared by passing a current of hydrosulphuric acid through diluted ammonia-water, till it ceases to give a white precipitate with a solution of sulphate of magnesium, which proves it to be saturated. It is more important as a compound of hydrosulphuric acid than of ammonia, and is largely employed as a means of distinguishing the metals from each other, being more useful for this purpose than the simple aqueous solution of that gas.

778. Ammonia has been considered along with potass and soda, because it so closely resembles them in alkaline properties, and because it forms salts exactly analogous to theirs. There are other reasons, however for discussing it along with the metals. Its compounds may be represented as containing a body, which, although it is not simple, as the metals, according to our present analyses, are, yet has the chemical properties of a metal, so that in combination it can play the part of one. This compound is called ammonium, and consists of gaseous ammonia *plus* an atom of hydrogen; or ammonia being NH_3, ammonium is NH_4. It forms one of the best marked examples of a compound *basyle.*

779. The compounds of the gaseous ammonia and the acids are represented as compounds of ammonium by transferring the hydrogen of the acid to the ammonia, which then becomes ammonium, and considering the radical of the acid as directly combined with the ammonium. Thus chloride of ammonium, NH_4Cl, is obtained by transferring the hydrogen from the hydrochloric acid, HCl, to the ammonia, NH_3.

780. This will appear more distinctly if we place in separate tables the same compounds, as salts of anhydrous gaseous ammonia, and as salts of ammonium.

Salts of Ammonia.

Hydrochlorate of Ammonia...	NH_3HCl	Earlier Method of naming ammoniacal compounds and representing them by symbols.
Hydriodate of Ammonia.......	NH_3HI	
Hydrobromate of Ammonia...	NH_3HBr	
Hydrofluate of Ammonia.......	NH_3HF	

Salts of Ammonium.

Chloride of Ammonium.........	NH_4Cl	Modern Method.
Iodide of Ammonium...........	NH_4I	
Bromide of Ammonium.........	NH_4Br	
Fluoride of Ammonium.........	NH_4F	

781. These salts, it will be observed, are, according to the second view, exactly comparable to the corresponding compounds of potassium and sodium, which they closely resemble. Thus, common salt, NaCl, sal-ammoniac, NH_4Cl, and the similar potassium compound, KCl, come to be the chlorides of sodium, ammonium, and potassium, each of which has the same common characters as a chloride. They agree in containing an atom of chlorine, united in two of them to an atom of a separable and apparently simple metal, and in the third to a non-isolable and compound metal, or, as it has been called, a *quasi*-metal, or basyle; that is, to a body which can discharge the functions, although it has not the constitution or physical characters, of an ordinary metal.

782. It is possible, indeed, that ammonium is not behind the isolable metals in the possession of even metallic splendour. There is a striking experiment, well worth repetition, which is thought to prove this. A small quantity of quicksilver is heated in a tube or porcelain basin, and one or two fragments of sodium added to it. The metals unite with evolution of heat and light. The resulting amalgam, which is liquid, like running mercury, is placed in a champagne glass, and covered with a saturated solution of sal-ammoniac. It instantly commences to swell up, and undergoes an enormous increase in volume, retaining all the while its metallic lustre, but exhibiting a consistence exactly like that of butter, so that if a dimple be made in it with a glass rod, a pit remains after the rod is withdrawn. The amalgam, indeed, provided it be kept under the surface of the liquid, may be moulded into any shape. Its great increase in volume is accompanied by a very trifling one in weight, the augmentation not being more than by about one twelve-thousandth part.

783. This curious compound is not permanent. Soon after its production it decomposes into mercury, hydrogen, and ammonia. It is thought possible that it may be a compound of ammonium and mercury, produced in virtue of the sodium of the amalgam combining with the chlorine of the sal-ammoniac, whilst the ammonium of the latter unites with the mercury, to form what has been called the ammoniacal amalgam; in symbols, NH_4Cl and $HgNa = NH_4Hg$ and $NaCl$. That such is its composition, however, cannot be demonstrated. Its instability makes an accurate analysis impossible.

784. The remaining salts of ammonia are represented as compounds of ammonium, by transferring the hydrogen of the essential atom of water in the free acid to the ammonia, so as to convert it into ammonium. The oxygen of the water is then considered as combined with the acid part of the ammonium compound, as in the corresponding salts of potassium and sodium. The following table will illustrate this:

Salts of Hydrated Ammonia.

Nitrate of Ammonia	$2NH_3$ and H_2O,N_2O_5 or $2(NH_3$ and $HNO_3)$
Carbonate of Ammonia	$2NH_3$ and H_2O,CO_2 or $2NH_3$ and H_2CO_3
Sulphate of Ammonia	$2NH_3$ and H_2O,SO_3 or $2NH_3$ and H_2SO_4

Salts of Oxide of Ammonium.

Equal to	Nitrate of Ammonium	NH_4NO_3
	Carbonate of Ammonium	$2NH_4,CO_3$
	Sulphate of Ammonium	$2NH_4,SO_4$

785. The nitrate of oxide of ammonium is thus likened to the nitrate of oxide of potassium (nitrate of potassium), which it resembles in many properties, becoming the nitrate of ammonium, NH_4NO_3, as we have the nitrate of potassium, KNO_3; and so on with the other salts.

786. There is a third compound of hydrogen and nitrogen, called amidogen, NH_2, which cannot be further considered.

787. *Tests for Ammonia or Ammonium in Combination.*—We have already mentioned fully the characters by which uncombined ammonia is recognised. We have now to state the mode

of identifying it, when it is in combination, for example, with an acid.

788. A solution of any salt of ammonium, except the carbonate, may be taken for the following experiments. A solution of the chloride of ammonium does best. Six glasses are half filled with this, and treated as follows:

To the first, sulphide of ammonium is added. No precipitate is given.

Phosphate of sodium and ammonia are added to the second. No precipitate. These negative results prove, as before, that the salt originally dissolved may be a compound of potassium, sodium, or ammonium.

789. To the third glass, solution of tartaric acid is added. No precipitate. The salt, therefore, is not one of potassium.

To the fourth glass, solution of perchloride of platinum is added. A yellow precipitate. The salt, therefore, is not a compound of sodium. It cannot, accordingly, be anything but a salt of ammonium. But this may be further proved by positive tests.

790. To the fifth glass, quick-lime or caustic potash is added. The odour of spirits of hartshorn is immediately evolved.

To the sixth glass, lime is also added, and the vessel put in a warm place. Moistened red litmus paper, or yellow turmeric paper, is held above the glass, care being taken that it does not touch the liquid. The former becomes blue, the latter brown.

791. There is, properly speaking, no blowpipe test for salts of ammonium. The great majority of them, when heated, are volatilised with or without decomposition, and are thus distinguished from salts of potassium and sodium, which are not volatile.

LITHIUM, CÆSIUM, RUBIDIUM.

792. Lithium is a white metal resembling sodium, with a specific gravity of 0·593, being the lightest known solid. Its oxide, lithia, Li_2O [old symbol, LiO], occurs in certain minerals, and in some mineral waters.

Cæsium and rubidium are metals resembling potassium and sodium, which are found in various states of combination in a few minerals, and in certain mineral waters.

METALS OF THE ALKALINE EARTHS.

CALCIUM, MAGNESIUM, BARIUM, STRONTIUM.

Calcium.

Combining proportion, 40; *symbol*, Ca.
[*Old combining proportion*, 20.]

793. Calcium is a rare metal, and is prepared by passing a galvanic current through fused chloride of calcium. It is a yellowish white metal, intermediate in hardness between lead and gold, and readily combines with the oxygen of the air or water. It is preserved in naphtha, and its combining proportion or atomic weight is 40. It derives its name from the Latin term for lime, *calx*, from which our English word calcareous is derived.

794. *Lime*, CaO.—Lime, or quick-lime, is obtained by heating limestone (carbonate of calcium) with coal to redness in a lime-kiln or open fire. The carbonic acid is totally expelled, and the oxide of calcium, lime, is left. Pure lime, such as may be procured by heating statuary marble or Iceland spar, forms a white, brittle, porous mass, which is highly caustic, and about three times heavier than water.

795. If sprinkled with water it first absorbs it, and then combines with it, forming a definite, dry hydrate. This process is called the slaking or slacking of lime, in allusion to its drinking up, as it were, the water poured on it. The quick-lime, or lime-shell, during the process of slaking evolves much heat, and finally crumbles into a fine powder, which is the hydrate, CaO,H_2O [old symbol, CaO,HO]. The temperature produced is sufficiently high to char and even to kindle wood. Carts conveying lime-shell have been set on fire in this way by a casual shower of rain, and similar accidents have occurred to sailing vessels from accidental leakage.

796. If the hydrate, CaO,H_2O, be exposed to a red heat, it parts with its water, and returns to the state of unslaked lime, CaO. Lime is often slaked in the laboratory, and then unslaked by heating it in a crucible in a furnace, as the most convenient way of obtaining it in the state of fine powder.

797. The hydrate of calcium is soluble in water to a small extent, and, curiously enough, is more soluble in cold than in hot water. This solution forms the well-known lime-water which is used in medicine, and kept in the laboratory as a test for carbonic acid.

798. All the facts we have mentioned may be easily verified by the student, who may make his own quick-lime by burning marble, or procure the former from a lime-kiln. With lime-water he may observe the properties which distinguish an alkaline earth from an alkali on the one hand, and from an earth proper on the other.

799. Lime-water is harsh to the taste, acrid, and caustic, as solutions of potass and soda are. Like them, it turns red litmus blue, purple cabbage green, and yellow turmeric brown. It differs from the alkalis in being much less soluble, and it forms insoluble salts with carbonic and phosphoric acids, whilst the corresponding salts of the alkalis are markedly soluble.

800. The two chief uses of lime are in the formation of building-mortar, and as an application to increase the fertility of the soil.

801. Ordinary mortar consists of lime made into a paste along with sand, and sometimes chopped hair. The object of the sand is to prevent the irregular contraction and cracking of the lime as it dries. The hair binds together the lime, and prevents its crumbling when very dry.

802. During the process of hardening, a certain amount of carbonic acid is absorbed by the mortar from the air, but in no case does the lime return entirely to the state of carbonate. The truth of this statement may be verified by mixing mortar from any old building with water, and then adding hydrochloric acid, which will be found to occasion only a slight effervescence.

803. Hydraulic mortar, or that employed for cementing the piers of bridges and other structures which are exposed to the action of water, consists of a natural or artificial mixture of limestone and ferruginous clay—that is, carbonate of calcium, and silicate of aluminum, containing iron. This is burned in a lime-kiln, and reduced to powder. When mixed with water, it sets as quickly as stucco, and finally becomes as hard as stone, in consequence of chemical combination occurring between the silica, lime, oxide of iron, and alumina. In ordinary mortar no such union occurs between the silica (the sand) and the lime.

804. The action of lime in fertilising soils is still matter of dispute. This much, however, appears to be certain: the efficacy of lime is most striking—first, on lands which are unfertile owing to excess of vegetable matter, such as bog, turf, or peat soils; and secondly, in stiff clay soils. It improves the first by causing the rapid decomposition of the excess of vegetable matter, so that the saline or mineral matter in the soil comes to bear a proportion to its vegetable or organic constituents, compatible with the healthy growth of plants in it.

805. On clayey soils lime appears to act beneficially by liberating the alkalis, especially potass. These are contained in the clay in union with its silica and alumina, so that rain-water cannot dissolve them and carry them into the tissues of plants. The lime, by combining with the silica and alumina, as it does in the hydraulic mortar, sets free the alkalis, which are then available for the nourishment of vegetables. The lime in this case is spread upon the land in autumn or winter, and the ground is not sown till spring.

806. *Salts of Lime or the Oxide of Calcium.—Carbonate of Calcium*, $CaCO_3$ [old name, Carbonate of Lime; symbol, CaO,CO_2], is one of the most widely distributed of salts, forming whole mountains of limestone and marble, besides being the chief constituent of shells, corals, coral reefs, chalk, &c. It likewise occurs crystallised in various shapes, but most strikingly in the rhombohedral form already referred to as characteristic of the

minority of the metals. It goes then by the name of Iceland, calcareous, or calc spar, and is celebrated for the striking way in which it exhibits double refraction of light, a remarkable phenomenon, which all transparent rhombohedral crystals shew, but none so markedly as Iceland spar.

807. The carbonate of calcium is insoluble, or nearly so, in pure water; but it dissolves readily in water containing carbonic acid, and in this condition, as held in solution by excess of carbonic acid, the carbonate of calcium exists in all natural waters, especially in *hard* waters. It is important as the source of quicklime, and of carbonic acid.

808. *Sulphate of Calcium, Gypsum, Alabaster, Stucco, Anhydrite, Selenite,* $CaSO_4$ [old name, Sulphate of Lime; symbol, CaO,SO_3].—This salt occurs in nature occasionally anhydrous, $CaSO_4$, and is then called anhydrite. It is much more abundant in combination with two atoms of water, $CaSO_4 + 2H_2O$. In this state it is called *gypsum.* The finer transparent varieties form the alabaster of the artist, and the selenite of the mineralogist. When gypsum is cautiously heated till it parts with the greater portion, but not the whole, of the water it contains, it forms plaster of Paris, or burned stucco. When this, in the state of powder, is made into a paste with water, it quickly forms a solid mass, or, as it is technically called, *sets.* In setting, the stucco takes back the water it was deprived of when heated, evolving heat in so doing, and returning to the same chemical state as the original gypsum.

809. If sulphate of calcium be deprived by heat of the whole of its water, it will not set when moistened, and it is scarcely possible to burn set stucco so as to make it set again.

810. Sulphate of calcium appears as a thick pasty precipitate when sulphuric acid is added to a strong solution of any salt of lime. It forms a striking experiment to add oil of vitriol to a saturated solution of chloride of calcium. So much of the sulphate is produced, that the whole liquid appears to solidify, and the vessel may be turned upside down without anything escaping.

811. Notwithstanding the fact just mentioned, sulphate of calcium is soluble in water to the extent of one part by weight of the salt in 460 of water. Such a solution is kept in the laboratory as a test, and will presently be referred to as enabling us to distinguish the alkaline earths from each other.

812. Permanently hard waters, which are not improved by boiling, generally contain sulphate of calcium. The lime may be got rid of by the addition of carbonate of sodium, which precipitates it as carbonate.

813. *Phosphates of Calcium.*—There are many compounds of lime and phosphoric acid, owing to the peculiarity of that acid in relation to the number of atoms of base it combines with at once. The most interesting phosphate of lime is that which occurs in bones, and is distinguished as the bone-earth phosphate, $3Ca,2PO_4$ [old symbol, $3CaO,PO_5$]. It has been already referred to under phosphorus.

814. *Chloride of Lime*, or *Bleaching Powder*, is more important as a compound of chlorine than as a salt of lime (par. 575). It has been discussed under chlorine.

815. The only remaining important compounds of calcium are the phosphide, fluoride, and chloride. The phosphide, CaP_2, has been described under hypophosphorous acid. The fluoride, CaF_2, is discussed under fluorine.

816. The *Chloride of Calcium*, $CaCl_2$, which must not be confounded with the chloride of lime, is an important salt. It is the residue of the process for carbonic acid by dissolving marble in hydrochloric acid (par. 373), and is produced in the course of other chemical processes on the large scale. It is extremely deliquescent, and has, especially when anhydrous, a great affinity for water. It is employed—1*st*, for freezing mercury; 2*d*, for drying gases; and it is likewise used, 3*d*, in the determination of the amount of hydrogen contained in organic bodies.

817. The tests for calcium in combination will be given after the other alkaline earths have been discussed.

Magnesium.

Combining proportion, 24; *symbol*, Mg.
[*Old combining proportion*, 12.]

818. Magnesium is obtained from its fused chloride by galvanic decomposition, or by heating the chloride of magnesium, $MgCl_2$, along with sodium, Na, when the latter combines with the chloride to form chloride of sodium, NaCl; and the magnesium, Mg, is obtained in a fused state, and can be cast into moulds. It is white, and readily fusible. It burns when heated in the air with a most dazzling brilliant flame, and forms its oxide, the familiar substance magnesia. It resembles zinc more than any of the other metals, and it is now prepared on the commercial scale, and used in the state of ribbon, wire, or powder, ignited by a gas flame, for producing a brilliant light suitable for illumination and for photographic purposes.

819. *Magnesia* is its only oxide. It may be obtained pure by heating the magnesia of the shops, which generally contains carbonic acid as well as water. It is a soft, white, light powder, which unites with water to form a hydrate, and dissolves in it, but only to a very small extent. It possesses causticity in a very feeble degree.

820. The solubility and alkalinity of magnesia are best observed by adding a spoonful or two of the powder to a solution of reddened litmus, purple cabbage, or yellow turmeric. The colours of all of them will be changed in the way already so frequently mentioned as characteristic of an alkali. If the magnesia were not soluble, it could not produce these effects.

821. Magnesia exists in nature abundantly in combination with carbonic acid, forming the carbonate of magnesium, $MgCO_3$, which is sometimes found singly, but more frequently presents itself in combination with carbonate of calcium, $CaCO_3$, forming magnesian limestone or dolomite, $CaCO_3 + MgCO_3$ [old notation, $CaO,CO_2 + MgO,CO_2$]. It is found also in many volcanic rocks, and in various minerals associated with other bases,

and in union with silica. Plants and animals contain it chiefly in union with phosphoric acid, and it is present in sea-water in considerable quantity, chiefly as the bromide, chloride, and sulphate of magnesium.

822. If a solution of caustic potash be added to concentrated sea-water, or, still better, to the bittern described under bromine (par. 638), it will occasion an abundant precipitate of hydrated magnesia. The bittern contains the sulphate of magnesium, $MgSO_4$, and the chloride of magnesium, $MgCl_2$, and the potash liberates the magnesia, as follows: $MgSO_4 + 2KHO = K_2SO_4$ and MgO,H_2O or MgH_2O_2; or $MgCl_2 + 2KHO = 2KCl$, and MgO,H_2O or MgH_2O_2.

823. *Carbonate of Magnesium,* $MgCO_3$ [old symbol, MgO,CO_2].—The carbonate has already been referred to. It is not easily obtained artificially. What is sold as such in the shops is prepared by the addition of a hot solution of carbonate of potassium or sodium to any soluble salt of magnesium, such as the sulphate. A white precipitate falls, containing four atoms of carbonic acid to five of magnesia and six of water. From this compound most of the other salts of magnesium may be obtained by dissolving it in the different acids.

824. *Sulphate of Magnesium,* $MgSO_4 + 7H_2O$ [old notation, $MgO,SO_3 + 7HO$].—Sulphate of magnesium, or Epsom salts, is prepared from bittern by evaporating it along with sulphuric acid; or by the action of oil of vitriol on magnesian limestone. In the latter process the resulting sulphates of calcium and of magnesium are separated from each other by digesting the mixture in a small volume of water, which takes up the readily soluble sulphate of magnesium, and leaves the greater part of the sulphate of calcium undissolved.

825. This salt is distinguished from the sulphates of the other alkaline earths by its great solubility, which is such that sulphuric acid does not occasion a precipitate in the strongest solutions of magnesian salts, whilst in these circumstances salts of calcium, barium, and strontium yield an abundant precipitate of their sulphates.

826. *Phosphate of Magnesium and Ammonium.*

$Mg,NH_4,PO_4 + 6H_2O$, or old notation, $2MgO,NH_4O,PO_5 + 12HO$.

If phosphate of sodium, or any other soluble salt of phosphoric acid, be added to sulphate of magnesium, a white precipitate slowly separates, consisting of the phosphate of magnesium, $Mg,H,PO_4 + 7H_2O$. If ammonia be added along with the phosphate of sodium, a crystalline precipitate appears at once, if the solutions are concentrated, and after some time if they are dilute. The precipitate consists of the phosphate of ammonium and magnesium, the formula of which is given above. The production of this salt, as we shall presently mention, supplies the means of identifying magnesium in combination.

827. The only important salts of magnesium are its chloride and bromide. The former, or chloride of magnesium, $MgCl_2$ [old notation, MgCl], is interesting as the source of the metal; the latter, or bromide of magnesium, $MgBr_2$ [old notation, MgBr], as the source of bromine. Both are very deliquescent, readily soluble in water, and have a very bitter taste.

Barium.

Combining weight, 137; *symbol*, Ba.

[*Old notation, combining weight*, 68·5; *symbol*, Ba.]

828. Barium is a yellowish white metal, and forms two oxides —the protoxide, BaO, and the peroxide, BaO_2. The latter is employed in the preparation of peroxide of hydrogen or oxygenated water, and will not be further alluded to.

829. The name barium is derived from the Greek adjective βαρυς (barys), heavy, in allusion to the conspicuous density of the native salts of this metal, which had long led to the sulphate being distinguished by the title of *heavy spar*.

830. The *protoxide*, BaO, called *Baryta* or *Barytes*, is prepared by heating the nitrate or iodate of barium in a crucible till the acid is expelled. The dry oxide forms a white, porous solid, which slakes like lime when moistened, with the evolution of heat, forming the hydrate of baryta, BaO,H_2O [old notation,

BaO,HO]. If boiling water be saturated with this, it deposits as it cools crystals containing one atom of baryta and nine of water, $BaO,H_2O + 8H_2O$. The liquid which yields these is a saturated cold solution of baryta, which will be found to act on colouring matters like an alkali, and to have a harsh, acrid taste. The solution, moreover, is caustic and poisonous. It is precipitated by carbonic acid still more readily than lime-water.

831. The salts of barium are interesting chiefly from their employment as tests for the mineral acids, and especially for sulphuric acid, as mentioned under that substance. The nitrate of barium is used in compounding green fire. The two most important are the *Chloride of Barium*, $BaCl_2$ [old notation, $BaCl$], and the *Nitrate of Barium*, $Ba2NO_3$ [old notation, BaO,NO_5]. They are prepared by dissolving the native carbonate of barium in hydrochloric and nitric acids respectively. When the carbonate cannot be procured, the sulphate of barium, a much more abundant mineral, is ground to powder, and heated with pulverised coal till it is reduced to sulphide of barium, BaS. The sulphide is then dissolved in the acid whose salt is desired. The native *Sulphate of Barium*, $BaSO_4$, or BaO,SO_3, is largely used in the compounding of pigments; and the artificial carbonate, $BaCO_3$, or BaO,CO_2, is employed in the analysis of minerals.

Strontium.

Combining weight, 87·5; *symbol*, Sr.

[*Old notation, combining weight*, 43·75; *symbol*, Sr.]

832. This metal derives its name from Strontian, in Argyleshire, in the lead-mines of which it is found as carbonate, sulphate, &c. The metal is yellowish white, and its protoxide, strontia or strontites, is prepared from the nitrate.

833. *Strontia*, SrO, forms a hydrate with water, and dissolves in it, forming a solution having properties similar to those of baryta-water. Its most important salts are the *Chloride of Strontium*, $SrCl_2$ [old notation, $SrCl$], and the *Nitrate of Strontium*,

$Sr2NO_3$ [old notation, SrO,NO_5]. With either of these bodies, the student may observe the only character of the strontia compounds which can be said to be of much interest.

834. They communicate to flame a splendid crimson colour, which leads to their employment in the arts for the production of red signal-lights and fireworks. This property may be well observed by throwing a large spoonful of the nitrate of strontium into a cinder fire, or, still better, by preparing what the pyrotechnists call red-fire. It consists of nitrate of strontium forty parts by weight, flowers of sulphur thirteen, chlorate of potassium five, sulphide of antimony four, all in fine powder. The chlorate of potassium must be pounded separately, and the materials mixed by gentle stirring in a wooden bowl or mortar. If pounded together, dangerous explosions will happen. The mixture, if taken in any quantity, must be fired in the open air, as it produces a large volume of sulphurous acid. The light it produces, when well prepared, is of the most intense red.

835. For an experiment within doors, a salt of strontia may be moistened with alcohol, and the latter set fire to. The chloride does better than the nitrate for this purpose, and the effect is very fine if a sheet of paper be kindled after being immersed in the solution. The red light may also be witnessed by heating the salts of strontia in the reducing blowpipe flame. Salts of barium, in similar circumstances, colour the flame green, but seldom distinctly. The pyrotechnist, however, prepares a fine 'green fire' by substituting nitrate of barium for the nitrate of strontium of the red fire.

836. Lime, in the reducing flame of the blowpipe, gives a flame somewhat like that of strontia, but duller, and more of a brick red. In the oxidising flame, lime produces an intense white light. Both of these appearances have been referred to already, under the oxyhydrogen blowpipe. Magnesia presents nothing particular in the inner blowpipe flame. In the outer one it evolves, like other infusible bodies, a bright white light.

837. *Tests for the Alkaline Earths in Combination.*—The

tests which we are about to describe apply equally to any of the soluble salts produced when the alkaline earths combine with acids. As all the salts, however, may be represented as produced by the solution of the alkaline earths in the different acids, we shall, to avoid unnecessary repetition, speak of salts of the alkaline earths.

838. The student, then, is first to prepare a saturated solution, or at least a strong one, of one salt of each of the alkaline earths. We shall suppose taken, what upon the whole are the most conveniently prepared, a solution of chloride of barium, one of chloride of strontium, one of chloride of calcium, and one of sulphate of magnesium.

839. These salts may be had to purchase, except perhaps the chloride of calcium, which can readily be prepared by dissolving white marble in pure hydrochloric acid. We shall distinguish the different salts simply by their metals, as salts of barium, strontium, calcium, and magnesium.

840. The first points to be observed, are certain characters which distinguish the alkaline earths, as a group, from the alkalis on the one hand, and the earths and remaining metals on the other.

841. To each of the four solutions contained in a wine-glass, sulphide of ammonium, NH_4HS, is added. It produces no precipitate. The only metallic salts in which this reagent produces no precipitate are salts of the alkalis and of the alkaline earths. Its negative action, therefore, shews us that we need not seek further for any of the earths or ordinary heavy metals, but it leaves undetermined whether each glass contains the salt of an alkaline earth or of an alkali.

842. To determine this, fresh portions of the four solutions are taken, and to each phosphate of sodium and ammonia are added. These produce in all of them white precipitates of the phosphates respectively of barium,, strontium, calcium, and magnesium. The alkalis, it will be remembered, gave no precipitate with the phosphate of sodium and ammonia. This one test, therefore, distinguishes the whole of the alkaline earths

from the whole of the alkalis. In other words, a dissolved salt, which is not precipitated by sulphide of ammonium, but is precipitated by phosphate of sodium and ammonia, can be nothing but the salt of an alkaline earth.

843. It remains, then, to discover whether it be a salt of barium, strontium, calcium, or magnesium.

844. Fresh solutions of the four are taken, and to each of them a saturated solution of sulphate of calcium is added. It will immediately produce in the salt of barium a white precipitate of sulphate of barium, $BaSO_4$. After some time, it will occasion in the salt of strontium a precipitate of sulphate of strontium, $SrSO_4$. But no precipitate will appear in the salt of calcium or of magnesium.

845. The cause of this difference is the relative solubility of the sulphates of the several alkaline earths. The sulphate of barium is quite insoluble in water, and appears in consequence at once. The sulphate of strontium has a certain solubility, and some time, accordingly, elapses before it shews itself. The sulphate of calcium cannot produce a precipitate in a salt of calcium, because there is more than enough of water present to retain dissolved all the sulphate of calcium that can possibly be formed. The sulphate of magnesium is greatly more soluble than the sulphate of calcium; so that if there be sufficient water present to prevent the latter precipitating, there must be enough to prevent the former.

846. A salt of barium is further distinguished from the other alkaline earths, by a solution of hyposulphite of sodium, $Na_2S_2O_3$, giving a white precipitate of the hyposulphite of barium, BaS_2O_3.

847. A salt of strontium is distinguished by giving no precipitate with the hyposulphite of sodium. The dry salt may be further tested at the blowpipe, or by kindling alcohol upon it, so as to see the crimson flame.

848. If a salt of an alkaline earth gives no precipitate with sulphate of calcium, it must be a salt of calcium or of magnesium. To discover which it is, a solution of oxalate of

ammonium, $2NH_4,C_2O_4$, is taken. It will give, with the salt of calcium, a white precipitate immediately of the oxalate of calcium, CaC_2O_4, but none with the salt of magnesium. No further test is needed for the lime salt; but in order to obtain a positive assurance that magnesia is present, a portion of the dry salt is placed upon charcoal, moistened with nitrate of cobalt, and heated in the outer flame of the blowpipe, when a skin-coloured residue will be obtained.

METALS OF THE EARTHS PROPER.

Aluminum or Aluminium.

Combining weight, 27·5; *symbol*, Al.

[*Old notation, combining weight*, 13·75; *symbol*, Al.]

849. The metal aluminum is prepared from the chloride Al_2Cl_6, or from a mineral called cryolite, a double fluoride, $Al_2F_6 + 6NaF$, or from the mineral bauxite, by means of the metal sodium and subsequent heating. Aluminum is white, with a bluish tinge resembling zinc, and is not very liable to tarnish or rust even when exposed to moist air. It is very light (2·56 to 2·67), being only about one-third the density of silver, and is manufactured into ornaments and trinkets of various kinds. It possesses great sonorous properties. It forms alloys with other metals. An alloy of 90 of aluminum and 10 of copper forms *aluminum bronze*, which resembles gold in general appearance.

850. The only oxide of the metal is a *sesquioxide* or *alumina*, with the symbol Al_2O_3. It occurs in nature abundantly, in combination with silica, associated with other bases. The most familiar, perhaps, of its native compounds is felspar, a silicate of aluminum and potassium, which occurs as one of the constituents of granite and of several other igneous rocks.

851. Certain varieties of these rocks, by exposure to the atmosphere, become completely disintegrated. It is the felspar which undergoes the change; and it appears to be owing to the action of rain-water charged with carbonic acid, which dissolves

the potass and some of the silica of the felspar, leaving the excess of silica and the alumina still united. By such a process of disintegration as we have described, the clays of our arable soils are produced. Clay consists of silica and alumina in a state of chemical combination. When it is pure, clay is quite white, as we see in the porcelain clay of Devonshire and Cornwall, which is derived from colourless felspar. More frequently clay is red, owing to the presence of red oxide of iron; or black, from the diffusion through it of vegetable matter.

852. When clay is boiled with oil of vitriol, the sulphuric acid combines with the alumina to the exclusion of the silica, forming the sulphate of aluminum, a highly soluble salt. From this pure alumina may be prepared, but the sulphate cannot always be readily obtained; and the student, in general, must have recourse to a compound of the sulphate of aluminum with the sulphate of potassium, which is largely consumed in the arts, and may always be easily procured. It goes by the name of alum.

853. From alum, alumina is prepared by adding to a solution of the former, aqueous ammonia as long as it occasions a precipitate. The alumina appears as a voluminous, white, gelatinous substance, consisting of the hydrated oxide of the metal $Al_2O_3 + 3H_2O$. In this state, after being gently dried, it is readily soluble in acids and in alkalis; but if heated to whiteness, it loses the associated water, contracts greatly in bulk, and forms a white, soft powder, not at all gritty or soluble in alkalis, and scarcely acted on by acids.

854. Alumina, whether hydrated or anhydrous, is insoluble in water, possesses no taste, and does not alter colouring matters. It is quite different, therefore, in properties from the alkaline earths, and is a much weaker base.

855. In the anhydrous state, it absorbs water with great readiness without combining with it, so that it adheres to the tongue, and is felt to parch it. Clay retains this property, and the ends of tobacco-pipes are glazed, to prevent adhesion to the lips or tongue.

856. Alumina is not fusible by a forge or furnace heat, but it melts before the oxyhydrogen blowpipe into a clear globule, possessing great hardness. It occurs in nature in a similar state. The more coarsely-crystallised specimens form the emery which is used for polishing; the transparent crystals, when of a blue colour, owing to a trace of metallic oxide, constitute the precious gem the sapphire, and when red, the ruby.

857. Alumina, in common with other sesquioxides, is a feeble base. The salts it forms with the acids have almost all a sour taste, and an acid action on colouring matter.

858. Alumina is not directly employed to yield the metal. If mixed, however, with charcoal, and heated red-hot in a porcelain tube passed across a furnace, whilst a current of chlorine is sent through the arrangement, the alumina parts with its oxygen to the carbon, and the chlorine takes the place of the former. In this way the chloride of aluminum is formed, Al_2Cl_6, a crystalline, volatile salt, which, when fused along with sodium, abandons its chlorine to form chloride of sodium, which remains as a scum on the surface, and leaves the metal aluminum at the bottom of the crucible.

859. SALTS OF ALUMINUM.—The chloride of aluminum is of special interest, and has been already referred to as a source of the metal aluminum. Some of the other salts of alumina are, however, of much more importance.

860. When alumina unites with an acid, a single atom of the earth combines with three of the acid. Thus the silicate of aluminum contained in felspar is $Al_2O_3,3SiO_2$, or $Al_2O_3,6SiO_2$. The same thing occurs with other sesquioxides, and it is a particular case of a general law, which teaches that the number of atoms of an acid which combine with an oxide to form a salt, is determined by the number of atoms of oxygen in the oxide.

861. Thus the alkaline earths all contain but one atom of oxygen. They all combine, accordingly, with one atom of acid, to form neutral salts. Alumina, on the other hand, Al_2O_3, sesquioxide of iron, Fe_2O_3, sesquioxide of manganese,

Mn_2O_3, oxide of chromium, Cr_2O_3, &c., all of which contain three atoms of oxygen, never unite with less than three atoms of an acid. So also the peroxide of tin, which is a binoxide, SnO_2, unites with two atoms of acid.

862. *Sulphate of Aluminum*, $Al_23SO_4 + 18H_2O$ [old notation, *Sulphate of Alumina*, $Al_2O_3,3SO_3 + 18HO$], has already been referred to as obtained by the action of sulphuric acid on clay. If raised to a red heat, the acid is expelled, and pure anhydrous alumina is left. The sulphate is largely used in dyeing and calico-printing.

863. *Sulphate of Aluminum and Potassium, Common Alum*, $Al_23SO_4,K_2SO_4 + 24H_2O$ [old notation, *Sulphate of Alumina and Potass*, $Al_2O_3,3SO_3 + KOSO_3 + 24HO$].—This valuable salt may be prepared by mixing solutions of sulphate of potassium and sulphate of aluminum, and allowing the liquid to evaporate spontaneously. The alum separates in large regular crystals, which are modifications of the cube and octohedron. It is generally, however, manufactured in another way.

864. At Hurlet, near Glasgow, at Whitby, in Yorkshire, and elsewhere, large beds of shale, or indurated clay, occur, associated with abundance of iron pyrites, the bisulphide of iron, FeS_2. The shale, or alum-schist, as it is called, is dug up, and broken into small pieces, which are piled in heaps, frequently wetted, and left exposed to the air. The pyrites rises in temperature as it absorbs oxygen, which converts its iron into protoxide of the metal, and each of its atoms of sulphur into sulphuric acid. The one of these combines with the oxide of iron, changing it into sulphate, FeO,SO_3, or $FeSO_4$. The other atom of sulphuric acid combines with the alumina of the shale, forming sulphate of aluminum, $Al_2O_3,3SO_3$, or Al_23SO_4.

865. As soon as this change has occurred, water is poured upon the alum-schist. It forms a solution of both the sulphates, which is concentrated by evaporation, and set aside to crystallise. The excess of the sulphate of iron, which is much less soluble than the salt of alumina, separates first, and is in greater part

removed in this way, being itself a valuable salt. Chloride of potassium is then added to the solution. It decomposes the remaining sulphate of iron, chloride of iron and sulphate of potassium being produced. The latter salt unites with the sulphate of aluminum and 24 atoms of water, and the triple compound separates as alum, whilst the chloride of iron, which is now the more soluble salt, remains in solution. The crystals of alum may be purified by resolution and recrystallisation.

866. Alum has a peculiar sour-sweet and astringent taste. It acts like a strong acid on colouring matter, and evolves hydrogen when zinc is added to its solution. It is used to a considerable extent in medicine. It is largely employed in the preparation of leather, and still more abundantly in dyeing, and in the preparation of pigments. Its application to the two latter purposes depends upon its attraction for organic colouring matters, and its affinity for textile tissues. The former property may be observed by adding to a solution of colouring matter, such as madder, cochineal, or litmus, first alum, and then an alkali, so as to precipitate the alumina. The latter, as it falls, will carry down the colouring matter combined with it. Such compounds are called *lakes*.

867. The attraction of alumina for the fibre of cloth may be shewn by filtering the acetate of aluminum, or a solution of common alum which has been partially neutralised by carbonate of sodium, through linen or cotton, when part of the alumina will be abstracted by these tissues, and retained.

868. Colours otherwise fugitive are thus fixed, the cloth to be dyed being first impregnated with alumina, and then immersed in an infusion of the colouring matter, or *vice versâ*. The alumina attaches itself to the fibre on the one hand, and the dye-stuff on the other, so that a coloured compound is produced, insoluble in water, and not destroyed by soap, &c.

869. Alumina, like other sesquioxides, does not readily combine with the weak acids, such as the carbonic. This may be shewn by adding carbonate of sodium to a hot solution of alum,

when carbonic acid will be observed to escape with effervescence. The white precipitate which falls is pure alumina, or contains only a small proportion of carbonic acid.

870. *Silicates of Aluminum.*—Silicates of aluminum, of constant composition, occur in various minerals, such as felspar, as we have already illustrated. The most interesting bodies of this class, however, are the clays, which are very variable in constitution, so that no common formula can be given for them.

871. Clay is an essential constituent of the important fabric pottery. Of this there may be said essentially to be but two kinds—earthenware and porcelain. Earthenware consists of clay alone, which, after being fashioned into vessels, and dried in the air, is exposed to a high temperature, in a peculiar furnace or kiln. In this state the burned clay forms a firm, solid, but brittle mass, which is porous, and pervious to water. It is quite opaque, exhibits no traces of fusion, breaks with an earthy fracture, and gives out, when struck, a dull sound.

872. To render earthenware fit to contain liquids, it is glazed: in other words, a fusible glass, reduced to powder, is made into a cream with water, and spread thinly over its surface. The vessel is then returned to the kiln, and heated till this coating melts, and forms an insoluble glassy varnish. Common salt is used as the glaze for the coarser articles, such as brown earthenware basins.

873. Porcelain, on the other hand, may be said to consist of clay and glass, the materials of which are ground to fine powder, and formed into a uniform paste with water. This paste is then dried till it resembles dough in consistence, and can then be formed into vessels. When these are heated in the kiln, the glassy element of the porcelain melts, and binds together its earthy constituent, at the same time rendering the whole mass more or less transparent, as wax does paper when melted into it, and then allowed to consolidate. Porcelain is distinguished from earthenware by being semi-transparent, by breaking with a glassy fracture, and by ringing like a metal when struck.

874. Various substances are employed as the glassy constituent of porcelain. Powdered flints are almost invariably made use of. Felspar is also used, so are phosphate of calcium (burned bones) and borax. Every celebrated pottery has its own recipe, and all the processes are kept very secret. Porcelain, like earthenware, requires to be glazed to render it impervious to liquids. Unglazed earthenware is largely employed in the construction of water-bottles for hot climates, where it is an object that the water shall slowly percolate through the walls of the vessel, and, by evaporation from its outer surface, cool the liquid within. For a similar reason, flower-pots are left unglazed, and so are the porcelain cells of galvanic batteries.

875. *Tests for Aluminum in Combination.*—A saturated solution of alum is prepared, and two glasses are half filled with it. To the first, sulphide of ammonium, NH_4HS, is added. It produces a white precipitate of hydrated alumina, $Al_2O_3,3H_2O$, as ammonia itself would do, hydrosulphuric acid separating as gas. This test distinguishes a salt of aluminum from the salt of an alkali, or an alkaline earth, as the two latter classes of compounds are not precipitated by sulphide of ammonium. We shall afterwards find that there is but one other metal—namely, zinc—whose salts give a white precipitate with the sulphide of ammonium.

876. To the second is added solution of caustic potass. The first addition of alkali occasions a white precipitate of hydrated alumina, $Al_2O_3,3H_2O$, but when more of the potass is added the precipitate re-dissolves. This clear liquid is divided into two portions. To the one of them, solution of hydrosulphuric acid is added; it will produce no precipitate. To the other, solution of chloride of ammonium; it will re-precipitate the hydrated alumina.

877. If a salt of alumina be heated on charcoal, at the outer blowpipe flame, after being moistened with solution of nitrate of cobalt, it will acquire a splendid blue colour.

878. BERYLLIUM OR GLUCINUM, YTTRIUM, ERBIUM, TERBIUM,

CERIUM, LANTHANUM, DIDYMIUM, ZIRCONIUM, NORIUM, and THORIUM are rare metals, found in a few minerals, and having properties and forming compounds similar to those of aluminum.

Chromium.

Combining weight, 52·5 ; *symbol*, Cr.
[*Old combining weight*, 26·25 ; *symbol*, Cr.]

879. Chromium is an interesting metal, from the variety and beauty of the colours of its compounds, which are largely used by the painter and dyer. It receives its name from the Greek χρωμα (chroma), colour. It differs much in properties from aluminum, but its salts behave with reagents as the compounds of the latter do. We discuss it here accordingly. Chromium forms two important oxides, the one a sesquioxide, Cr_2O_3 ; the other chromic acid, CrO_3.

880. The different compounds of chromium are procured from a mineral called *chrome iron ore*, which can be readily procured from any dealer in minerals. Its composition is $FeO + Cr_2O_3$. A portion of this is to be ground to powder, and heated in a crucible with a mixture of carbonate and nitrate of potassium. The oxygen of the nitre combines with both the metallic oxides, converting the one into the peroxide of iron, Fe_2O_3, and the other into chromic acid, CrO_3, which unites with the alkali, forming chromate of potassium, K_2O,CrO_3, or more strictly, K_2CrO_4, a lemon-yellow salt, which is dissolved when water is digested on the contents of the crucible. A small portion of sulphuric acid is added to the dissolved chromate of potassium. It combines with one-half of the alkali, leaving the other in combination with two atoms of chromic acid, forming a rich orange-red salt, easily crystallised, the bichromate of potassium, $K_2Cr_2O_7$ [old notation, $KO,2CrO_3$].

881. Large quantities of this salt are prepared from chrome iron ore by the process just described, and from this salt, which can be readily obtained, all the other compounds of chromium are prepared.

882. *Oxide*, Cr_2O_3.—The oxide, which contains exactly half as much oxygen as chromic acid, is prepared from the bichromate of potassium by heating it in a crucible alone, or along with sulphur, to a full red heat, and afterwards washing the contents of the crucible with water, and drying them.

883. The bichromate, heated alone, yields the oxide in dark-green crystals of great beauty. The product is not so beautiful, but is twice as abundant, when sulphur is used. The oxide is employed in painting and glass-staining. As procured by the processes described, it is anhydrous, and insoluble in acids. It is obtained hydrated by raising a solution of bichromate of potassium mixed with hydrochloric acid to the boiling-point, and adding alcohol in small quantities at a time, till the liquid changes from orange to green. The alcohol deprives the chromic acid of half its oxygen, reducing it to the oxide which forms with the hydrochloric acid, the perchloride of chromium, Cr_2Cl_6.

884. From this liquid, caustic potass precipitates the hydrated oxide of chromium, $Cr_2O_3 + 3H_2O$, of a blue-green colour. Sulphide of ammonium has the same effect, acting on salts of chromium as it does on those of aluminum, precipitating the hydrated oxide of the metal, $Cr_2O_3 + H_2O$, and not a sulphide. A dry salt of chromium is most easily identified by fusing it with nitre, so as to observe the change from green or purple to yellow, which attends the conversion of the metal into chromic acid, and the consequent formation of chromate of potassium, which dissolves in water, and yields, with acetate of lead, a yellow precipitate.

885. *Chromic Acid*, CrO_3.—This acid is obtained almost pure by mixing a cold saturated solution of bichromate of potassium with half as much again of oil of vitriol. The sulphuric acid combines with the potass, evolving much heat, and the chromic acid separates in beautiful red crystals as the liquid cools. Chromic acid is exceedingly soluble, and cannot be brought into contact with organic matter, owing to the readiness with which the latter deprives it of half its oxygen. Bichromate of

potassium and sulphuric acid (yielding chromic acid) are employed to bleach palm-oil.

886. The salts of the acid are more important than itself. The *Chromate* and *Bichromate of Potassium* have already been referred to. The *Chromate of Lead*, *Chrome Yellow*, PbO,CrO_3, or $PbCrO_4$, largely used in the arts, is produced by precipitating a solution of acetate of lead by bichromate of potassium. If the chromate of lead be boiled with lime-water, or fused with nitre, half the chromic acid is transferred to the alkaline base, and a *Dichromate of Lead*, $2PbO,CrO_3$, or $2Pb,CrO_5$, of a beautiful orange-red, scarlet, or vermilion colour, is left.

887. *Chromate of Silver*, Ag_2O,CrO_3, or Ag_2CrO_4, is produced by mixing solutions of bichromate of potassium and nitrate of silver. It is a purplish-brown powder, which, when crystallised from its solution in dilute nitric acid, is of a splendid ruby-red colour. The red tint of the ruby is due to the presence of chromic acid. The *Chromate of Mercury* is brick-red.

888. *Chlorochromic Acid*, $CrO_2 + Cl_2$.—This interesting compound is made by mixing equal weights of bichromate of potassium and common salt, and distilling them, along with oil of vitriol, in a glass retort provided with a receiver. The substance in question rises as a deep-red vapour somewhat resembling hyponitric acid, but redder in colour, and condenses into a heavy liquid like bromine in appearance.

889. The vapour of chlorochromic acid is more irritating to the lungs than chlorine, and excites violent coughing even in the most healthy persons. If dropped upon sulphur or alcohol, it sets them on fire. It is at once decomposed by water.

HEAVY METALS, OR METALS PROPER.—I. METALS NOT PRECIPITABLE IN THEIR ACID SOLUTIONS BY HYDROSULPHURIC ACID—ZINC, IRON, MANGANESE, COBALT, NICKEL.

Zinc.

Combining weight, 65·2; *symbol*, Zn.

[*Old combining weight*, 32·6; *symbol*, Zn.]

890. Zinc occurs in nature chiefly as calamine stone, the native carbonate of the protoxide, ZnO,CO_2, or $ZnCO_3$, and as zinc-blende, ZnS, the sulphide of the metal.

891. The carbonate is reduced by mixing it with coke or charcoal, and exposing it in peculiarly-constructed crucibles to a red heat. The carbonic acid of the ore is expelled by the high temperature, and the charcoal removes the oxygen of the metallic oxide, forming carbonic oxide. The zinc rises in vapour, and distilling over, is received in water.

892. Zinc-blende is first roasted—that is, heated in a current of air, which burns away its sulphur, and converts it into oxide, and the latter is then treated like the calamine stone.

893. Zinc is a bluish-white metal, which slowly tarnishes in the air to a slight depth, in consequence of superficial oxidation, and is then protected by this film from further tarnishing.

894. The density of this metal is from 6·8 to 7·3. At ordinary temperatures, unless perfectly pure, it is highly crystalline and brittle; but if heated to 250° up to 300°, it becomes quite malleable, and may be rolled out into sheets, as it now is extensively, being cheaper than lead and tin, for which it is substituted.

895. It melts at about 773°, and at a red heat rises in vapour, taking fire in open vessels, and exhibiting a rich yellow-green flame, somewhat resembling that of phosphorus when burning in a limited supply of air, but of a finer green. This appearance may be readily observed by heating zinc in a Hessian or fire-clay

crucible in a common grate till the zinc begins to burn. It must be occasionally stirred, so as to secure the free admission of the air necessary for its combustion. The zinc, as it burns, is converted into a white flock-like substance, to which the alchemists gave the name of philosophers' wool. It is the protoxide of zinc carried up in the current of warm air.

896. Zinc is largely consumed, as a substitute for lead, in roofing houses, and instead of tin-plate for the construction of milk-pails and similar vessels. It is much employed, also, in the manufacture of galvanic batteries; and in combination with copper, as the important alloy brass, is of extensive application in the arts. It is interesting to the chemist as the ordinary source of hydrogen, which it furnishes when dissolved in the dilute acids. Its salts, also, are employed in the arts, and largely in medicine.

897. *Oxide of Zinc*, ZnO.—Zinc forms but one oxide, closely resembling magnesia in appearance and properties. It is prepared by burning the metal in air; by heating the carbonate till the carbonic acid is expelled; or by adding caustic potass to the solution of a salt of zinc, such as the sulphate, when the oxide is precipitated as a gelatinous, white hydrate, ZnO,H_2O, or ZnH_2O_2. If excess of alkali be added, the oxide of zinc, like alumina in similar circumstances, dissolves, forming a clear solution.

898. When the oxide of zinc is exposed to a low red heat, it becomes yellow; but when it cools to the ordinary temperature, it recovers its original white colour.

899. *Salts of Zinc.—Sulphate of Zinc*, $ZnSO_4 + 7H_2O$ [old symbol, $ZnO,SO_3 + 7HO$].—This salt, it will be remembered, was the residue of the process for hydrogen by the solution of zinc in diluted sulphuric acid (see par. 271). The sulphate is used to a considerable extent in medicine, and is commonly called *white vitriol*.

900. *Chloride of Zinc*, $ZnCl_2$ [old symbol, $ZnCl$], is prepared by dissolving zinc, the oxide of zinc, or the carbonate of zinc, in hydrochloric acid. The metal combines with the chlorine,

and hydrogen is evolved. The dry salt is highly deliquescent, and soluble in water and alcohol. An aqueous solution is extensively employed as an antiseptic and disinfectant, under the name of *Burnett's Disinfecting Fluid.* Wood saturated with it is said not to suffer from the dry rot; and it arrests the decay of animal matters, and decomposes offensive gases, such as the hydrosulphuric acid of sulphide of ammonium, so as to prove of service on board crowded ships, in hospitals, &c.

901. *Tests of Zinc.*—A solution of sulphate of zinc is to be prepared, which must be free from iron. If it give a black precipitate with sulphide of ammonium, and a brown one with caustic potass, iron is present. Most commercial specimens of sulphate of zinc contain this impurity; and if a pure specimen cannot be obtained, a solution must be prepared by dissolving the oxide of zinc in diluted sulphuric acid.

902. To the dissolved salt of zinc a few drops of pure hydrochloric acid are added, and three test-glasses are half filled with it. To the first, solution of hydrosulphuric acid is added. It will produce no precipitate. This property is common to zinc, and all the metals of the division to which it belongs. Its importance will appear hereafter.

903. To the second glass, sulphide of ammonium is added. It produces a white precipitate of hydrated sulphide of zinc, ZnS,H_2O [old symbol, ZnS,HO], the only white sulphide known. To the third glass, caustic potass is added, drop by drop. The first additions of the alkali occasion a white precipitate of hydrated oxide of zinc, ZnO,H_2O [old symbol, ZnO,HO]. The succeeding additions of potass redissolve this, so that the liquid becomes clear again.

904. The second and third tests, it will be observed, produce the same effect upon a salt of zinc as they do upon one of alumina. The potass solution from the third test is divided into two portions. To the one, solution of chloride of ammonium is added, and it will produce no precipitate. This proves the salt not to be one of aluminum. To the other portion, solution of hydrosulphuric acid is added, and it will throw down a white

precipitate of the hydrated sulphide of zinc, ZnS,H_2O. This proves the salt to be one of zinc.

905. There are, besides, two blowpipe tests: The sulphate of zinc, or any other dry salt of the metal, is mixed in the state of powder with carbonate of sodium, and heated on charcoal in the reducing flame of the blowpipe. The charcoal becomes incrusted with a yellow powder, which changes to white when it cools. This appearance is owing to the production of oxide of zinc, and is characteristic of the metal. A more easily-tried, and more striking blowpipe test, is to moisten a salt of zinc with solution of nitrate of cobalt, and heat it in the outer flame. It acquires a rich green colour.

906. Certain zinc ores contain a small proportion of a metal called INDIUM, which has recently been discovered by means of spectrum analysis. It is known by the symbol In, and has the combining weight of 71·8. It forms a series of compounds, and, either alone or in combination, it gives rise to a deep blue tint when held in any flame.

Iron.

Combining weight, 56; *symbol*, Fe (Ferrum).

[*Old combining weight*, 28; *symbol*, Fe.]

907. Iron occurs native to a small extent, uncombined with any other substance. Thin veins of the metal are found traversing certain rocks, only, however, in quantities sufficient to be objects of curiosity. Iron also occurs so pure as to be malleable in many of those remarkable bodies, the meteoric stones, in association with nickel and other metals, but with a mere trace of non-metallic matter.

908. The economical sources of this metal, however, are its native oxides and carbonate, which form its most abundant ores.

909. Magnetic iron ore, or the black oxide Fe_3O_4, is abundant in various parts of the world. It can be easily reduced to the metallic state by heating it simply with coke or charcoal, and the iron which it yields affords a much finer steel than that

furnished by the metal reduced from the more complex ores which abound in this country.

910. The red oxide of iron also, Fe_2O_3, called by mineralogists Hæmatite, when it occurs pure, is as easily reduced, and as valuable an ore, as the black oxide.

911. The most abundant and important, however, of the iron ores is the clay iron-stone, which consists of the carbonate of iron associated with clay, the carbonates of calcium, magnesium, and manganese, as well as coaly matter. This ore contains, on an average, about 30 per cent. of metallic iron. It requires a much more complex process for its reduction than the native oxides.

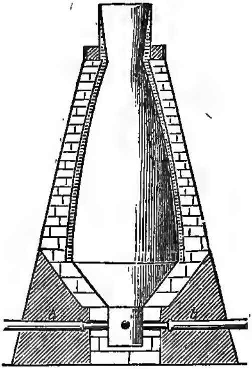


Fig. 58.

912. The clay iron ore is first roasted or calcined, during which process it parts with any water it may contain, and with the carbonic acid and coaly matter. The roasted ore is then introduced into a blast furnace (fig. 58), which resembles in construction a conical or domed chimney, fifty or sixty feet in height, and about sixteen in diameter within at the widest part. The ore, and the materials required for its reduction, are introduced by the top; and a high temperature is maintained by forcing in air through tubes called tuyères (*b*, *b*) near the bottom of the furnace, through the medium of an air-pump, fanners, or any other convenient form of blower.

913. At one time cold air was employed for this purpose, and the furnace was fed with coke; but in the progress of time an immense improvement has been effected by heating the air before it is driven into the furnace. The air is raised in temperature by being made to traverse a series of tubes heated by a fire, and arranged between the blowing apparatus and the furnace. It is thus heated to between 600° and 700°, which is found the most suitable temperature. This is called the *hot*

blast. It enables the iron-master to substitute raw coal for coke, and effects a saving of more than three-fourths of the coal which was requisite when the cold blast was employed.

914. Along with the calcined iron-stone and fuel, limestone is introduced into the furnace. The object of this addition is to detach the clay (silicate of aluminum) from the oxide of iron, so as to permit the fuel to act upon the latter. This the lime does by combining with the clay, so as to form a fusible glassy compound (the silicate of calcium and aluminum).

915. The oxide of iron, freed from the clay, readily parts with its oxygen to the fuel, and in one part of the furnace is believed to be present in the state of pure or malleable iron; but as this descends, it unites with the white-hot carbon of the coal, forming a fusible carbide of iron, which accumulates at the bottom of the furnace in the liquid state, with the fluid silicate of calcium and aluminum floating above it. These liquids are drawn off at intervals by different apertures; the latter when it consolidates, forms the slag of the furnaces; the former is run into channels of sand, and constitutes the cast-iron or pig-iron of commerce.

916. Cast-iron, it will be observed, is not pure iron, but a compound of the metal with carbon. The latter occurs in it to the extent of about five per cent., which is nearly one atom of carbon to four of iron. Besides carbon, however, some silicon, derived from the silica of the clay, as well as manganese and phosphorus, and perhaps also calcium, magnesium, and aluminum, are present in small quantity.

917. It is possible also that the rare metal TITANIUM is present. Minute red sparkling crystals of a compound of titanium are very frequently found imbedded in the slags and bricks within the blast furnaces, when any circumstance leads to these being blown out.

918. Cast-iron differs from malleable iron in being much more fusible, in possessing a highly crystalline structure, and in being greatly more brittle. Liquid cast-iron expands in becoming solid, and in consequence takes very sharp impressions from a mould, its increase in bulk causing it to insinuate itself into the finest

lines, and so to present a faithful copy of each. This fact is not to be confounded with another, which has led to its being denied—namely, that an iron casting is always smaller than the wooden fac-simile, or original, from which its mould was made. This diminution of size is owing to the contraction of the iron *after* it has consolidated. It has swelled up into every crevice of the mould, however, before contraction commences.

919. Malleable iron is prepared in this country from cast-iron by depriving the latter of carbon. The process by which this is done is called *puddling.* This is effected in a reverberatory furnace (see fig. 59)—that is, one somewhat resembling a baker's oven, where the current of burning gases proceeding from the hot fuel, A, is reflected or made to reverberate downwards from the arched roof of the furnace to the floor, B, so as to expose a body lying on the latter to a great sheet of flame and of hot air.

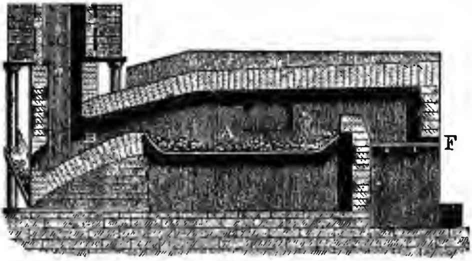


Fig. 59.

920. The cast-iron is laid in the bed of the furnace, B, where it speedily melts, and becomes partially oxidised at the surface. The workman then, by means of a long iron rod, or large oar-like spatula, puddles the melted metal—that is, stirs it up, so as to bring each portion of it successively to the surface. The object of the whole process is to remove the impurities from the cast-iron. The silicon and phosphorus are oxidised and removed in the slag or scum, whilst the carbon is converted into carbonic

oxide, and as the removal of the carbon proceeds, jets of that gas are seen burning on the surface of the metal with its characteristic blue flame.

921. One marked effect of the withdrawal of the carbon from the cast-iron is the diminution of its fusibility, so that although the temperature of the furnace remains unaltered, the metal ceases to be liquid, and becomes first pasty, and then, as the stirring or puddling is continued, granular—that is, like coarse-grained sand. The temperature of the furnace is now rapidly raised, till the sand-like particles of metal begin to grow pasty, and to agglutinate, a property of iron referred to already under welding. The workman then, with his puddling-rod, gathers together the particles of iron into large balls, which are removed from the furnace, and exposed on suitable anvils to large tilting or steam-hammers, driven by machinery. These squeeze out of the balls, as from a sponge, any portion of the cast-iron still liquid within them, and at the same time weld the particles of iron together into one solid coherent mass.

922. The block of iron thus procured is heated a second time, and passed between large iron rollers, furnished with grooves, which convert the mass into a long rod or bar. Iron which is to sustain a great strain, such as that for anchor-shanks, or the axles of railway-carriages, undergoes this process several times, the long bar being cut into several short ones, which are tied side by side with iron wire, raised to a high red heat, forged on the anvil, and passed between the grooved rollers again and again. Great tenacity is thus given to the metal.

923. The bar or malleable iron thus procured is not crystalline in structure, or nearly so brittle as cast-iron. Its texture is fibrous, which is well seen by immersing a wire in a dilute acid, and allowing the latter to act till it dissolves to some slight depth the outer surface. The toughness and fibrous character of malleable iron slowly disappear if it be exposed to continued violent concussion, in consequence, as is believed, of the development of a crystalline structure, so far analogous to that which

is always present in cast-iron. Several of the dangerous accidents on our railways which have resulted from the breaking of carriage-axles, are referred to such a development of brittle crystalline structure in the iron of the axle, in consequence of the concussions to which it is exposed during the rapid motion of a railway-train.

924. The malleable iron of commerce is never quite free from carbon, and contains, in addition to about one-half per cent. of it, small quantities of silicon and the various metals present in cast-iron. (See par. 916.)

925. Malleable iron is converted into steel by adding carbon to it, to a smaller extent, however, than it occurs in cast-iron. Only the purest iron, reduced from its native oxides, is employed for this purpose. Bars of this iron are placed in alternate layers with charcoal powder in iron boxes, and the whole exposed to a high red heat for forty or fifty hours. At the end of that period the iron, without having undergone fusion, is found to have combined with about one and a half per cent. of carbon, and also some nitrogen. For its finer applications, the bars of steel are welded together under the tilting hammer, which gives the steel greater uniformity of composition and texture; and for the finest cutting instruments, it is melted, cast into ingots, and afterwards forged.

926. The manufacture of steel suitable for many purposes has recently been much expedited and cheapened by the introduction of a plan of working known as Bessemer's process, which consists in taking the fused cast-iron and forcing a stream of air through the red-hot fluid mass. The greater part of the carbon in the cast-iron is burned off, and in about twenty minutes the blast of air is shut off, and a little molten cast-iron containing manganese, but otherwise very pure, being run into the crucible, the steel is ready to be poured out into a mould.

927. Steel is much less fusible than cast-iron, but much more so than malleable iron. It is, on the other hand, inferior to the latter in malleability. The most important character of steel is the property it possesses of acquiring great hardness and

elasticity, if raised to a high temperature, and then rapidly cooled, as by plunging it into oil or cold water. The steel at the same time becomes very brittle. If, on the other hand, it be slowly cooled from a red heat, it becomes soft, like malleable iron, loses its brittleness and elasticity, and does not readily take or keep a sharp edge.

928. By varying the temperature to which it is raised, and the rapidity with which it is cooled, it may be obtained of all degrees of hardness, from that given to files, which will scratch glass, down to that of a pallet-knife or spatula. Articles of steel are generally forged and cooled quickly. They are then heated a second time to a temperature which is the higher the softer the steel is intended ultimately to be, and from this temperature they are permitted to cool slowly. This is called the *tempering* of steel.

929. Pure iron, which is very rarely seen, has, when polished, a white colour and brilliant lustre. Its specific gravity is 7·844. It can be rendered magnetic by various processes, but does not retain its magnetism if pure. The addition of oxygen, sulphur, and carbon in certain proportions renders it susceptible of permanent magnetism.

930. Iron does not rust in dry air, but becomes rapidly oxidised if moistened, or under water, at the expense partly of the oxygen of the dissolved air, partly of the water, which it can decompose if carbonic or any other acid be present. The circumstances under which iron decomposes water have been discussed under hydrogen (pars. 269 and 270). Quevenne's iron, as used in medicine, is the metal in a fine state of division.

Compounds of Iron.

931. *Oxides.*—There are three well-known oxides of iron, which act as bases, and one acid oxide:

Protoxide.................	FeO	Black Oxide..............	Fe_3O_4
Sesqui or Peroxide......	Fe_2O_3	Ferric Acid...............	FeO_3

932. The last is a weak and unstable metallic acid. The

black oxide has already been referred to as the magnetic iron ore. (See par. 909.) It is the substance produced when iron wire is burned in oxygen, and it may be obtained by other processes. Though named as a separate oxide, it may be represented as a compound of the two oxides first mentioned, or $FeO + Fe_2O_3$. It is occasionally called, accordingly, the proto-peroxide of iron.

933. *Protoxide.*—The protoxide of iron is an important compound, from the many salts it forms with acids. It is not easily obtained pure, owing to its great affinity for oxygen, and its proneness to pass into the peroxide. To procure it, a solution must be freshly prepared by dissolving clean iron wire in diluted sulphuric acid in the cold. When caustic potass is added to this solution, a precipitate falls of the hydrated protoxide, FeO,H_2O, or FeH_2O_2 [old symbol, FeO,HO], which is first white, then green, then gray; and if boiled with water, out of contact with the air, becomes quite black; if exposed to the air, it becomes reddish brown, from absorption of oxygen and conversion into the hydrated sesquioxide. The salts which this oxide forms have all, when pure, a pale-green colour.

934. *Peroxide.*—The peroxide or sesquioxide of iron, Fe_2O_3, has been already referred to as an ore of iron (see par. 910). When anhydrous, it is red; when hydrated, it is brown. It is often called the red oxide of iron. It is procured anhydrous by calcining green vitriol, the prosulphate of iron. As mentioned under Nordhausen sulphuric acid (par. 491), the protoxide of this salt becomes peroxide, at the expense of one half of the sulphuric acid of the sulphate, which it reduces to the state of sulphurous acid.

935. It is obtained as a hydrate by adding water of ammonia to a solution of green vitriol, which has been boiled with a little nitric acid till its colour changed from green to brown. The alkali throws down the oxide as a reddish-brown precipitate. It forms salts with acids, which are all of a brown colour.

936. *Chlorides.*—There are two chlorides of iron—the lower

or simple chloride, $FeCl_2$, prepared by dissolving iron in cold diluted hydrochloric acid; and the perchloride, Fe_2Cl_6, which is prepared by dissolving the peroxide, Fe_2O_3, in hydrochloric acid.

937. *Iodides.*—There are two similar iodides of iron—the lower iodide, FeI_2, made by digesting iodine and iron-filings with water. It is used in medicine. The periodide, Fe_2I_6, is unimportant.

938. *Sulphides.*—The protosulphide, FeS, has been already referred to under hydrosulphuric acid (par. 505), in the preparation of which it is largely consumed in the laboratory.

939. The bisulphide or iron pyrites, FeS_2, to which there is no corresponding oxide, has also been noticed under sulphur and alum. (See pars. 468 and 864.) It occurs in roofing-slates and elsewhere in yellow glistening metallic-looking crystals, and also in a massive state, especially in the neighbourhood of coal-fields. It is largely employed as a source of sulphur in the manufacture of sulphuric acid (par. 495).

940. Both the protoxide and peroxide of iron form, as already mentioned, salts with acids; so that, for example, we have a sulphate of the protoxide and a sulphate of the peroxide; and in like manner two nitrates.

941. To distinguish these two classes of salts from each other, without employing so long a title as, for example, sulphate of the protoxide of iron, sulphate of the peroxide of iron, the salts are simply named protosulphate, and persulphate of iron; the prefix not referring directly to the proportion of the acid in the salts, but to the composition of their component oxide. All the salts of the peroxide, in virtue of the law mentioned under aluminum, contain for each atom of base three atoms of acid.

942. The protosulphate of iron, $FeO,SO_3 + 7H_2O$, or $FeSO_4 + 7H_2O$ [old, $FeO,SO_3 + 7HO$], has already been sufficiently referred to under Nordhausen sulphuric acid and alum (pars. 491 and 864).

943. The persulphate, $Fe_2O_3,3SO_3$, or Fe_23SO_4, is prepared by adding to the protosulphate, dissolved in water, half as much

sulphuric acid as it contains already. The solution is then raised to the boiling-point, and nitric acid is added, drop by drop, as long as the liquid darkens. It is then evaporated to dryness, and redissolved.

944. The protonitrate of iron, FeO,N_2O_5, or $Fe2NO_3$ [old, FeO,NO_5], is unimportant. The pernitrate, $Fe_2O_3,3N_2O_5$, or Fe_26NO_3 [old, $Fe_2O_3,3NO_5$], is used in dyeing.

945. The protocarbonate of iron, FeO,CO_2, or $FeCO_3$, has been already referred to as a constituent of clay ironstone. It is prepared artificially by adding a solution of carbonate of potassium or sodium to the dissolved protosulphate of iron. It then shews itself as a whitish-green precipitate, which, if dried, parts with its carbonic acid, and absorbs oxygen, becoming converted into the hydrated peroxide.

946. The protocarbonate is soluble in water containing much carbonic acid, and exists in this state in many of the chalybeate waters, which are distinguished by their inky taste, and the rust or ochre which they deposit when exposed to the air. The peroxide of iron forms no salt with carbonic acid.

47. *Tests for Iron in Combination.*—The same tests act differently with iron, according to its state of combination; a salt of the peroxide, for example, giving a different-coloured precipitate from that produced with a compound of the protoxide. We accordingly distinguish tests for a protosalt of iron from those for a persalt. A protosalt is either a salt of the protoxide, or a compound having a composition similar to that of the oxide, such as the protochloride, $FeCl_2$. All protosalts of iron are green. A persalt either contains the peroxide, or resembles that oxide in composition, such as the perchloride, Fe_2Cl_6.

948. *Tests for a Protosalt of Iron.*—Protosalts of iron are with difficulty prevented from absorbing oxygen, and passing in part into the state of persalts, in which case they do not act distinctly with the tests. It is best, therefore, to prepare, shortly before use, a solution, by digesting clean iron wire in diluted sulphuric acid. Portions of this are to be put into test-glasses,

and the following tests, which, to avoid repetition, are understood to be taken in solution, made use of:

949. To the first glass, hydrosulphuric acid is added, and no precipitate is given. To the second, sulphide of ammonium is added, and a black precipitate of the protosulphide of iron, FeS, is obtained, which is soluble in hydrochloric acid. To the third, caustic potass is added, and a whitish-green precipitate of the hydrated protoxide of iron, FeO,H_2O, or FeH_2O_2, is thrown down, which slowly changes to brown.

950. To the fourth glass, ferrocyanide of potassium (the yellow prussiate of potass) is added. A bluish-white precipitate is given, which gradually changes into dark blue (Prussian blue). To the fifth glass, ferridcyanide of potassium (red prussiate of potash) is poured in, and a deep-blue precipitate (a variety of Prussian blue) is given.

951. *Tests for a Persalt of Iron.*—The persulphate, $Fe_2O_3,3SO_3$, or Fe_23SO_4, or the perchloride, Fe_2Cl_6, may be taken indifferently as specimens of a persalt. The one or other is dissolved in water, and treated with the same tests as the protosalt.

952. Hydrosulphuric acid produces a white precipitate, consisting of sulphur, separated from the hydrosulphuric acid, the hydrogen of which has united with the oxygen of the peroxide, or the salt radicle (for example, chlorine) of the persalt.

953. Sulphide of ammonium gives a black precipitate of the sulphide of iron, FeS (not Fe_2S_3), soluble in hydrochloric acid. Caustic potass affords a brownish-red precipitate of the hydrated peroxide, $2Fe_2O_3,3H_2O$. Ferrocyanide of potassium gives a deep-blue precipitate of Prussian blue. Ferridcyanide of potassium yields a brown colour, but no precipitate; and sulphocyanide of potassium gives a blood-red solution.

Manganese.

Symbol, Mn; *combining proportion*, 55.
[*Old combining weight*, 27·5; *symbol*, Mn.]

954. Metallic manganese is a hard, brittle metal, with a grayish-white colour, and is obtained by heating pure oxide

of manganese or the carbonate with sugar charcoal and oil in a crucible lined with charcoal. It is known only as a chemical curiosity. Several compounds of the metal are used in the arts.

955. *Oxides.*—There are no fewer than seven oxides of manganese. Of these, however, two are unimportant. The remainder have the following composition:

Protoxide	MnO
Sesquioxide or Deutoxide	Mn_2O_3
Peroxide, Binoxide, or Black Oxide	MnO_2
Manganic Acid	MnO_3
Hypermanganic Acid	Mn_2O_7

956. *Protoxide.*—The protoxide is obtained anhydrous by heating its carbonate in a stream of hydrogen gas. It appears as an olive-green powder. It is better known in the state of hydrate, as obtained by precipitating one of its soluble salts by an alkali. It appears then as a yellow-white substance, rapidly becoming buff-coloured, and then brown, owing to absorption of oxygen from the air, and its conversion into a higher oxide.

957. *Sesquioxide,* Mn_2O_3.—This body is the brown substance into which the hydrated protoxide changes by exposure to the air. It is a much weaker base than the corresponding oxide of iron, or than alumina; but it can unite with acids, such as the sulphuric, and form salts.

958. *Peroxide,* MnO_2.—This oxide has already been referred to under oxygen and chlorine. It is the condition in which manganese is generally found native, and is termed the black oxide of manganese. It occurs native abundantly, and is largely consumed in the preparation of bleaching-powder, as well as for other purposes.

959. *Manganic Acid,* MnO_3, is obtained in combination with potass by heating in a crucible the black oxide of manganese, along with that alkali and a little nitrate or chlorate of potassium. The peroxide, MnO_2, by combining with an atom of oxygen, becomes manganic acid, MnO_3. This afterwards unites with the alkali, forming the manganate of potassium, K_2O,MnO_3,

or K_2MnO_4 [old symbol, KO,MnO_3]. This substance goes by the name of *mineral chameleon*, in consequence of the curious changes in colour which it undergoes when dissolved in water. The student should prepare it for the sake of observing these.

960. Mineral chameleon is of a green colour, and if dissolved in a small quantity of cold water, forms a beautiful dark-green solution. If this be slowly diluted with a large quantity of water, the green begins to exhibit shades of red, and various tints, produced by the intermixture of red, green, and blue, successively appear, till ultimately the liquid acquires a deep purple colour. These changes occur much more rapidly if the manganate of potassium, dissolved in a little cold water, be afterwards diluted with the same liquid at the boiling temperature.

961. *Hypermanganic Acid*, Mn_2O_7.—The purple liquid obtained by the action of hot water on mineral chameleon is a solution of the hypermanganate of potassium, K_2O,Mn_2O_7, or $K_2Mn_2O_8$ [old symbol, KO,Mn_2O_7]. Its production from the manganate is attended by the separation of hydrated peroxide of manganese, which appears as a brown powder, and subsides.

962. Three atoms of manganic acid contain altogether 3 atoms of manganese and 9 of oxygen. One of the atoms of manganese separates along with two atoms of oxygen as the peroxide, whilst the remaining seven atoms of oxygen, along with the two of manganese, form an atom of hypermanganic acid; in symbols, $3MnO_3 = MnO_2$ and Mn_2O_7.

963. *Chloride of Manganese*, $MnCl_2$ [old symbol, $MnCl$].—This salt is left as the residue of the process for chlorine when hydrochloric acid and the black oxide of manganese are used. It is always, however, contaminated by iron, from which it may be purified in various ways. The simplest, perhaps, is to evaporate the impure liquid completely to dryness, and then to heat it to low redness in a crucible. By this process the iron is either expelled as the volatile perchloride, or changed into the insoluble peroxide, so that when the heated mass is digested in water, only the chloride of manganese dissolves.

964. The purity of the chloride of manganese from iron may

be ascertained by adding to the liquid the ferrocyanide of potassium, which should produce a pinkish-white, and not a blue precipitate. If the latter appears, iron is present. To get rid of it, a portion of the solution has carbonate of sodium added to it, as long as it occasions a precipitate, which is in greater part the carbonate of manganese. This carbonate is boiled with the original liquid, and deprives it of iron by converting the latter into the insoluble peroxide. From the pure chloride the other salts of manganese are prepared.

965. *Tests for Manganese.*—A solution of the pure chloride of manganese is divided amongst three test-glasses, and the following tests are added:

Hydrosulphuric acid gives no precipitate.

Sulphide of ammonium yields a flesh-coloured precipitate of sulphide of manganese, MnS. It changes to a dark brown when exposed to the air, but as originally produced is quite peculiar in tint, and is characteristic of compounds of manganese.

Potass produces a precipitate of the hydrated protoxide, MnO,H_2O, or MnH_2O_2 [old symbol, MnO,HO], which is first white, then buff-coloured, and finally dark-brown. These appearances, also, are quite distinctive of manganese salts, and no more tests than the three given are necessary for the recognition of dissolved protosalts of the metal.

966. There are also two blowpipe tests applicable to any manganese compound.

The salt or other compound of manganese is mixed with carbonate of potassium or sodium, and melted in the loop of a platinum wire at the outer flame of the blowpipe, when mineral chameleon is produced, easily recognised by its green colour. This test is very delicate.

The experiment is repeated with the substitution of biborate of sodium (borax) for carbonate of sodium. A clear transparent bead is obtained of a violet colour. It becomes colourless if exposed to the inner blowpipe flame. Manganese in the state of oxide is the colouring matter of the amethyst, and is employed to give glass a violet tint.

Cobalt and Nickel.

967. Cobalt and nickel are two metals having the same general characters as the others of the group which have been discussed. Both are used in the arts, but they are not of sufficient chemical interest to call for detailed notice. The combining proportion of cobalt is 59 [old notation, 29·5]; symbol, Co. Reference has already been made to the employment of the nitrate of cobalt in blowpipe testing. It gives with salts of alumina, when exposed to the outer blowpipe flame, a deep blue; with salts of zinc, a green; and with salts of magnesia, a pale rose or pink colour. Its protoxide is a well-known black powder, and stains glass of a deep blue. It is largely employed for this purpose and for colouring porcelain. Compounds of cobalt are very easily detected by mixing them with borax, and heating them in the outer blowpipe flame. A transparent bead of an intense blue colour is produced.

968. The chloride of cobalt forms sympathetic ink. When concentrated, its solution is rose-coloured, but if sufficiently diluted, characters written with it on paper are invisible when dried in the air. If the paper, however, be heated, or otherwise strongly dried, they appear of a deep blue. The characters again become invisible if removed from the source of heat, or cause of dryness, owing to the absorption of moisture. The changes in colour depend upon the fact, that the anhydrous chloride of cobalt is blue, whilst the same salt hydrated is of a pale rose colour.

969. The combining weight of nickel is 59 [old notation, 29·5]; symbol, Ni. Its chief importance is in the manufacture of the substitutes for silver-plate, which are sold under the name of German silver, nickel silver, &c. They consist of copper, zinc, and nickel, combined in different proportions. The salts of nickel have all a rich green colour in solution. They are readily distinguished from other bodies by giving—no precipitate with hydrosulphuric acid; a black precipitate with sulphide of ammonium, insoluble in hydrochloric acid; a green precipitate with caustic potash; with ammonia a similar precipitate,

which dissolves in excess of the alkali, forming an azure solution; and with cyanide of potassium, a yellowish-green precipitate soluble in excess.

II. METALS PRECIPITABLE BY HYDROSULPHURIC ACID, IN NEUTRAL, ACID, OR ALKALINE SOLUTIONS—COPPER, LEAD, SILVER, MERCURY, BISMUTH, AND CADMIUM.

Copper.

Combining proportion, 63·5; *symbol*, Cu (Cuprum).
[*Old combining weight*, 31·75; *symbol*, Cu.]

970. Copper is an abundant and valuable metal, and occurs native. Its chief ores are copper pyrites, a combination of the sulphides of iron and copper, $Cu_2S + Fe_2S_3$, and the carbonate of copper or malachite, $CuO,H_2O + CuO,CO_2$, or $CuH_2O_2 + CuCO_3$, which is the most easily reduced of all the ores of the metal.

971. Copper is the only red metal. It is nearly nine times heavier than water, its specific gravity being 8·921 to 8·952. It is highly malleable and ductile, and an excellent conductor of heat and of electricity. It fuses or melts at 1996° F., and when poured into a mould, it does not take a sharp impression. Our copper coins, accordingly, are not cast, but stamped, and the metal is chiefly wrought with the hammer. Brass consists of copper and zinc, and bronze of copper and tin.

972. In moderately dry air, copper slowly acquires a brown tarnish, which is quite superficial, and is probably owing to the formation of a thin film of suboxide, Cu_2O. In damp air it acquires a green crust, from the formation of the carbonate.

973. Oxides of Copper.—Copper has two oxides, each of which forms salts with acids: the one is the protoxide, and is also called the black oxide, CuO; the other is a suboxide, and is distinguished as the red oxide, Cu_2O.

974. *Protoxide*, CuO.—The protoxide may be prepared in various ways: By heating sheet-copper in a furnace to a red heat, with free exposure to air, till it becomes uniformly black;

by raising the nitrate to a red heat in a crucible; or by precipitating a salt of the oxide, such as the sulphate, by caustic potass. This gives the hydrated oxide, CuO,H_2O, or CuH_2O_2 [old symbol, CuO,HO], which is blue; but if the liquid be raised to the boiling-point, it loses the water, and becomes dark brown and anhydrous, CuO. This oxide, as obtained by calcining the nitrate, is employed in organic analysis. Its salts are all green or blue.

975. *Suboxide*, Cu_2O.—For each atom of copper there is but half an atom of oxygen; so that when we indicate it by symbols, we write it Cu_2O. It occurs native, of great beauty, in transparent octohedral crystals of a ruby-red colour. It may be obtained artificially, by heating together five parts of the black oxide of copper with four of copper filings, or by boiling a solution of sulphate of copper with caustic potass and honey. The sugar of the honey deprives the protoxide of half its oxygen, and the suboxide precipitates as a brown-red powder. The majority of its salts are colourless, and exceedingly prone, like most salts of lower oxides, to absorb oxygen, and pass into compounds of a higher base. When heated with glass, it gives it a beautiful ruby-red colour, which, however, is somewhat difficult to secure, owing to the readiness with which the suboxide passes by absorption of oxygen into the protoxide, which colours glass green.

976. SULPHATE OF COPPER, or BLUE VITRIOL, has the symbol $CuSO_4 + 5H_2O$ [old symbol, $CuO,SO_3 + 5HO$], and is prepared on the large scale by oxidising the sulphide of copper, or by dissolving the old copper-sheathing of ships, after calcination in a furnace, in diluted sulphuric acid. It forms large, regular, blue crystals, twice as soluble in hot as in cold water. This salt is employed in medicine, in dyeing, and in the preparation of pigments.

977. NITRATE OF COPPER, $Cu2NO_3 + 6H_2O$ [old symbol, $CuO,NO_5 + 3HO$].—A deep blue, crystalline, very deliquescent, and corrosive salt. It is prepared by dissolving copper, or its oxide or carbonate, in nitric acid, and evaporating the liquid;

when on cooling, crystals of the nitrate of copper separate. Its chief employment is in the production of the black oxide of copper for organic analysis.

978. CARBONATES OF COPPER.—Combinations of oxides of copper with carbonic acid, in various proportions, occur native, and are wrought as ores, or manufactured into ornamental articles. Malachite, which is cut into slabs like marble, and fashioned into vases, is a subcarbonate, consisting of two atoms of oxide of copper with one of carbonic acid and one of water, $CuO,H_2O + CuCO_3$ [old, $CuO,HO + CuO,CO_2$]. Another carbonate, called chessylite, has the symbol $CuO,H_2O + 2CuCO_3$ [old, $CuO,HO + 2CuO,CO_2$]. A precipitate of the same composition is obtained by mixing solutions of carbonate of sodium and sulphate of copper.

979. CHLORIDE OF COPPER, $CuCl_2$ [old symbol, $CuCl$].—The chloride is prepared by dissolving the black oxide in hydrochloric acid, and concentrating till crystals form. It is soluble in alcohol, and the solution burns with a rich green flame, like that which boracic acid exhibits.

980. TESTS FOR COPPER.—The salts of the suboxide of copper are rarely met with. The following tests apply to salts of the black oxide, or protosalts. A saturated solution of sulphate of copper is taken, and the following tests are applied to it in as many glasses:

981. Hydrosulphuric acid produces a black precipitate of sulphide of copper, CuS. This test would alone distinguish a salt of copper from salts of all the metals already discussed.

Sulphide of ammonium yields the same precipitate.

982. Potass produces a greenish-blue precipitate of the hydrated oxide, CuO,H_2O, or CuH_2O_2 [old, CuO,HO], which becomes black when boiled with water.

Ammonia in small quantity produces a greenish-blue precipitate, which, when the alkali is added in greater abundance, is dissolved, forming an azure-blue solution.

Ferrocyanide of potassium (the yellow prussiate of potash) produces a reddish-brown precipitate of ferrocyanide of copper.

This test shews best with a dilute solution, and is a very delicate test for copper.

983. If a plate of clean iron or steel be immersed in a solution of the sulphate, or any other protosalt of copper, it is almost immediately covered with a thin layer of metallic copper. This of course is the most decisive of all tests, as the metal itself is seen, and the peculiarity of its colour excludes the possibility of its being confounded with any other.

984. If any salt of copper be mixed with carbonate of sodium, and heated on charcoal in the inner blowpipe flame, metallic copper is obtained, of its characteristic colour. From the preceding statements, it will be learned that no metal is more easily detected in combination than copper. The tests are easily applied, and are almost all very delicate.

Lead.

Combining weight, 207 ; *symbol*, Pb (Plumbum).

[*Old combining weight*, 103·5 ; *symbol*, Pb.]

985. The principal ore of lead is the sulphide (galena), which generally contains silver as well as lead, in combination with sulphur. By calcination in a current of air it is converted in part into sulphate of lead, $PbSO_4$, and by subsequent increased heat the whole is reduced to the state of metal.

986. The carbonate (white lead), when it occurs in sufficient abundance, is also wrought as an ore. By far the larger proportion of the lead of commerce, however, is obtained from galena.

987. Lead is a soft blue metal, easily scratched, even by the nail, and producing a mark upon paper. It is highly malleable, but not very ductile. Its specific gravity is 11·36. It melts at 617° F., and boils and passes into vapour at a white heat. It slowly tarnishes in dry air, and the film of oxide produced protects it from further change.

988. Under the surface of water free from salts, such as rain or distilled water, lead becomes rapidly converted into

oxide and carbonate, which in part dissolve in the water, and render it poisonous, so that very soft waters cannot be conducted through lead pipes, or kept in leaden cisterns. If the water, however, contain (as spring, well, and river water generally does) sulphates and chlorides, then insoluble salts are formed, which incrust the lead, and prevent the water being contaminated. A minute quantity of saline matter is sufficient to prevent water becoming poisonous by contact with lead; but when nitrates are present in the water, the lead is dissolved to a dangerous extent.

Oxides of Lead.

Protoxide, PbO; Red Oxide, Pb_3O_4; Peroxide, PbO_2.

989. *Protoxide—Litharge, Massicot,* PbO.—Lead is converted into this oxide by exposing it whilst melted to a current of hot air; likewise by heating the carbonate of lead to low redness. When carefully prepared, and not allowed to fuse, it is of a pale-yellow colour, and is named *massicot;* but if raised to a red heat, it fuses, and crystallises on cooling of a brick-red colour. In this state it is called *litharge.* It forms, when boiled with oil, the sticking-plaster of the surgeon. It enters largely into the composition of flint-glass, on which it confers brilliancy and fusibility, and it forms a large number of important salts by union with the different acids.

990. RED OXIDE, RED LEAD, or MINIUM, Pb_3O_4.—This substance is prepared by heating massicot to low redness whilst a current of air flows over its surface. It is employed chiefly as a pigment, and is known in commerce as red-lead or minium.

991. *Peroxide of Lead—Brown or Puce Oxide,* PbO_2, is obtained by pouring dilute nitric acid on red-lead; the latter resolves itself into protoxide, which unites with the nitric acid, and peroxide, which is left as an insoluble purplish-brown powder.

992. SALTS OF LEAD—*Carbonate of Lead, White-Lead,* $PbO,H_2O + 2PbCO_3$ [old symbol, $PbO,HO + 2(PbO,CO_2)$].—This is the most important salt of lead, from its great consumption in painting. It is used not only as a white pigment, but is

mixed with the majority of colours used in house-painting, with a view to confer upon them *body* or *opacity.* In virtue of this quality, which it possesses in a high degree, a thin layer of it suffices to conceal and cover a previous coating of paint. It has the great disadvantage, however, already referred to, of blackening by hydrosulphuric acid. The carbonate may be prepared on the small scale by mixing solutions of carbonate of sodium and acetate of lead. It is prepared on the large scale with excess of oxide, which increases its opacity.

993. *Nitrate of Lead,* $Pb2NO_3$ [old symbol, PbO,NO_5].—This salt is readily obtained by digesting lead, its protoxide, or its red oxide in nitric acid, and concentrating till crystals separate. It is interesting as a source of hyponitric acid, N_2O_4, when heated. It has been used as a disinfectant.

994. *Acetate of Lead,* or *Sugar of Lead,* $Pb2C_2H_3O_2$ [old symbol, $PbO,C_4H_3O_3$].—This salt is referred to here although its acid has not yet been described, because it is the salt of lead most easily procured, and, upon the whole, most suitable for exhibiting the tests of lead. It is prepared by dissolving litharge in vinegar, and receives its vulgar name from its intensely sweet taste, and also, perhaps, from its resemblance in appearance, as usually sold, to loaf-sugar.

995. To avoid repetition, the other compounds of lead will be referred to under its tests. A solution of acetate of lead is to be made with rain or distilled water, and afterwards filtered. To this, in separate glasses, the following tests are to be added:

996. Hydrosulphuric acid, and sulphide of ammonium, precipitate the black sulphide of lead, PbS.

Caustic potass produces a white precipitate of the hydrated oxide, PbO,H_2O, or PbH_2O_2, and if added more abundantly, dissolves this, producing a clear liquid.

Carbonate of sodium throws down a white precipitate of the carbonate of lead, PbO,CO_2, or, more strictly, $PbCO_3$.

997. Sulphuric acid produces a white precipitate of the highly insoluble sulphate of lead, PbO,SO_3, or, more strictly, $PbSO_4$, soluble in excess of potash.

Hydrochloric acid produces a crystalline white precipitate of the chloride of lead, $PbCl_2$ [old symbol, PbCl], soluble in much water.

Iodide of potassium gives a brilliant yellow precipitate of the iodide of lead, PbI_2 [old symbol, PbI].

Bichromate of potassium produces a bright yellow precipitate of chromate of lead, PbO,CrO_3, or, more strictly, $PbCrO_4$.

Silver.

Combining weight, 108; *symbol*, Ag (Argentum).

998. Silver occurs native as the uncombined metal, as sulphide, and as chloride. From the latter it is procured by tedious and complicated processes. It is obtained pure for chemical purposes by the following process, which the student may repeat with any fragment of sterling silver, such as a defaced coin.

999. The metal is dissolved in pure nitric acid, in which it will disappear with great rapidity, forming the nitrate of silver, $AgNO_3$, and causing the evolution of much nitric oxide. The solution will have a green colour, from the copper with which silver is purposely alloyed, and provided the nitric acid has been perfectly free from hydrochloric acid, a small amount of black powder will generally remain undissolved. This is gold, which it was not worth while to separate from the silver when it was reduced from its ore.

1000. To the clear liquid which contains the nitrates of silver and of copper, a solution of common salt is added as long as a precipitate falls. This is the insoluble chloride of silver, AgCl, the copper remaining in solution. The chloride is washed, dried, and melted in a crucible, along with anhydrous carbonate of sodium. Chloride of sodium is produced, and metallic silver, which consolidates, after fusion, into a pure brilliant knob or button.

1001. Silver is the whitest of the metals, and is excelled by none in lustre. It is one of the best conductors of heat and of electricity, and is preferred to all other metals in the construction of delicate electrical instruments where long metallic wires are required.

1002. Silver does not oxidise in air or in water, but it becomes rapidly tarnished from the action of hydrosulphuric acid upon it. It enters into combination with oxygen when melted with glass, communicating to it at the same time a yellow colour, for which purpose it is employed in glass-staining.

1003. *Protoxide of Silver,* Ag_2O [old symbol, AgO].—This oxide is obtained in the state of a hydrate by adding caustic potass to a solution of nitrate of silver. It appears as a pale-brown precipitate, which, when dry, is very unstable. Light and heat both occasion evolution of oxygen and separation of metallic silver. The only very important salts of silver are the nitrate and the chloride.

1004. *Nitrate of Silver,* or *Lunar Caustic,* $AgNO_3$ [old symbol, AgO,NO_5].—This salt is sold in little sticks about the diameter of a quill, for the convenience of the surgeon. They are produced by fusing the nitrate, and pouring it into moulds. The salt, however, can be readily obtained in crystals by dissolving pure silver in nitric acid, and concentrating the solution.

1005. *Chloride of Silver,* AgCl, has already been referred to under hydrochloric acid, and the purification of silver. It is obtained by mixing solutions of any soluble chloride, and almost any salt of silver. When heated, it fuses, and crystallises, on cooling, into a substance resembling horn in appearance and softness, and is then called *horn silver.*

1006. All the salts of silver, when in contact with vegetable or animal matter, blacken when exposed to light. Marking-ink consists essentially of a solution of nitrate of silver thickened with gum, and occasionally, to prevent its corroding action, mixed with ammonia.

1007. The beautiful designs produced in photography on paper or glass in different shades are obtained by saturating the paper with various salts of silver, such as the chloride, bromide, iodide, nitrate, gallate, &c., and then exposing it to the regulated action of light. Wherever the light falls, the paper darkens, owing to the production of a suboxide of silver, and at times of the reduction and separation of the metal itself.

1008. TESTS FOR SILVER.—A solution of nitrate of silver is taken, and to one portion of it hydrosulphuric acid is added. It produces a black precipitate of sulphide of silver, Ag_2S. To a second portion hydrochloric acid is added. It produces a white precipitate of the chloride of silver, AgCl.

1009. The liquid containing the chloride of silver may be divided into two portions. To the one nitric acid is added, and it produces no effect; to the other ammonia, and it dissolves the chloride of silver, producing a clear solution.

Caustic potash produces a light-brown precipitate of the hydrated oxide of silver, AgHO [old symbol, AgO,HO].

Mercury or Quicksilver.

Combining weight, 200; *symbol*, Hg (Hydrargyrum).

[*Old combining weight*, 100; *old symbol*, Hg.]

1010. Mercury occurs native uncombined, but more abundantly as sulphide, forming the ore called cinnabar, which is identical in composition with vermilion, HgS. The metal is procured by roasting the ore or by heating the cinnabar along with iron turnings or lime.

1011. The student may imitate the process on the small scale by mixing vermilion with quicklime in a test-tube, and applying heat. The red colour will rapidly disappear, as the sulphur combines with the calcium of the lime, which gives off its oxygen, whilst the mercury condenses in globules in the cool part of the tube.

1012. Mercury is the only element, except bromine, liquid at ordinary temperatures. From this character, and its silvery colour, it receives its ordinary name of quicksilver. It has, however, a shade of blue.

1013. It becomes solid at the temperature of $-39°$ F. It is then soft, ductile, and malleable. It rises in vapour at any temperature above 40° F., and dangerous accidents have occurred on board ships conveying it from South America, in consequence of leakage of the vessels containing it, and the poisonous action of the mercurial vapour on the crew and living creatures in the vessel. It boils at 662° F.

1014. Liquid mercury has the specific gravity (at 60°) 13·54. It contracts greatly when it solidifies, so that the density of frozen mercury is 14.

1015. Mercury does not alter in the air in ordinary circumstances, nor does it tarnish, if pure. When heated in contact with air to a temperature ranging between 700° to 800° F., the mercury becomes oxidised, or *rusts*, with the formation of the red oxide, HgO.

1016. It forms two oxides, which are generally distinguished by their colour; the lower, which is a suboxide, Hg_2O, being named the gray or black oxide; the higher or protoxide, HgO, the red oxide.

1017. The *suboxide of mercury*, Hg_2O, is prepared by adding caustic potass to its nitrate, $HgNO_3$, or, more conveniently, by shaking together calomel, $HgCl$, and lime-water. It is a dark gray, nearly black, heavy powder, readily decomposed both by heat and by the sun's rays. It forms salts with acids.

1018. The *red oxide of mercury*, HgO, also called red precipitate, is procured by heating mercury in a flask for some days at a temperature above 600°, or by heating its nitrate, $Hg2NO_3$, till the acid is expelled. The oxide is left as an orange-red crystalline body.

1019. The red oxide may also be procured by adding caustic potass or lime-water to a solution of the bichloride of mercury or corrosive sublimate, $HgCl_2$. It appears as a yellow precipitate, paler in colour than the crystallised oxide. It yields pure oxygen when heated (par. 237) and may be employed for that purpose.

1020. *Chlorides of Mercury.*—There are two chlorides which possess great medicinal importance, and deserve special notice: the subchloride, calomel, HgCl [old symbol, Hg_2Cl], and the perchloride, corrosive sublimate, $HgCl_2$ [old symbol, HgCl].

1021. *Corrosive sublimate* is prepared by mixing the sulphate of the red oxide of mercury, HgO,SO_3, or, more strictly, $HgSO_4$, with an equal weight of common salt, and applying heat to the mixture contained in a small retort. The chlorine of the chloride of sodium combines with the mercury, forming the bichloride or perchloride of mercury, which rises in vapour, and condenses as a crystalline sublimate. The sodium of the salt remains behind in combination with the oxygen and sulphuric acid previously united to the mercury. The fixed residue, accordingly, is sulphate of sodium. The change may be thus stated in symbols:

$$HgSO_4 + 2NaCl = Na_2SO_4 \text{ and } HgCl_2.$$

1022. Corrosive sublimate is soluble in water, alcohol, and ether. It is a deadly poison, and serious accidents have occurred from its substitution for calomel. It forms an insoluble compound with white of egg, which is administered as an antidote to its poisonous effects.

1023. To prepare the lower chloride of mercury or *calomel*, the sulphate of the red oxide has as much metallic mercury as it contains already, ground with it in a mortar. It is then mixed with one half of its weight of common salt, and the whole heated in a retort. Calomel, which, as well as the higher chloride, is volatile, rises in vapour, and condenses in crystals.

1024. The sulphate of the black oxide, Hg_2SO_4, cannot be prepared readily, but the mechanical mixture of mercury and the higher sulphate is equivalent to a salt of the black oxide. The most convenient mode of procedure is to take any quantity of mercury, and divide into halves by weight. The one half is boiled with oil of vitriol, till it forms the sulphate of the red oxide, $HgSO_4$. It is then dried and triturated in a mortar with the other half of the quicksilver, and the resulting mixture is sublimed along with half its weight of common salt. The change which occurs is as follows:

$$HgSO_4 + Hg + 2NaCl = Na_2SO_4 \text{ and } 2HgCl.$$

1025. Calomel, unlike corrosive sublimate, is quite insoluble in water, and much less poisonous than the higher chloride. The student should be careful, when preparing it or corrosive sublimate, to avoid inhaling the vapours of the volatilising salts, as salivation is readily induced by a small amount of either chloride of mercury when it enters the body by the lungs.

1026. It is necessary also to point out that the scientific names of calomel and corrosive sublimate have been frequently changed in consequence of alterations of opinion as to the atomic weight or combining proportion of mercury, some representing it, as is done in this book, as 200, others as half that number, or 100. If the atomic weight be made 200, calomel is the chloride, $HgCl$, and corrosive sublimate the bichloride, $HgCl_2$. If 100, calomel becomes the subchloride, Hg_2Cl, and corrosive sublimate the protochloride, or simply the chloride, $HgCl$.

1027. The protochloride of one person approving of one atomic weight, thus comes to be the bichloride of another employing a different combining proportion, which may lead to dangerous results when the chlorides of mercury are purchased for medicinal use, since the fraction of a grain of the higher chloride is a sufficient dose, and a party who had corrosive sublimate given to him instead of calomel would, in the majority of cases, receive a fatal dose. It is best, therefore, to distinguish them by their trivial names of calomel and corrosive sublimate; but if it is deemed necessary to use chemical titles, it will be found safest to call calomel the *sub*chloride, and corrosive sublimate the *per*chloride, although these are not according to strict theory.

1028. There are two *iodides of mercury*. The higher, HgI_2, has been referred to under hydriodic acid. There are two *sulphides.* The higher is the valuable pigment vermilion, which is black as prepared by the full action of hydrosulphuric acid on a solution of corrosive sublimate, but becomes red when sublimed. There is a nitrate of each of the oxides of mercury. That of the black oxide, $HgNO_3$ [old symbol, $Hg_2'O,NO_5$], is obtained by dissolving mercury in cold diluted nitric acid. The nitrate of the red oxide, $Hg2NO_3$ [old symbol, HgO,NO_5], is procured by dissolving the metal in strong hot nitric acid. The sulphate of the red oxide, HgO,SO_3, or $HgSO_4$, is obtained by boiling mercury and oil of vitriol together.

1029. TESTS FOR MERCURY.—Salts of mercury may be identified by mixing them dry with anhydrous carbonate of sodium, and heating the mixture. The metal, rising in vapour, condenses in globules in the cool part of the tube; and a piece of bright copper introduced into a solution of mercury is coated with a silver stain.

1030. A distinction is made in testing between salts of the black oxide and those of the red. The more common salt of the lower oxide is the nitrate, $HgNO_3$, and this gives:

With hydrosulphuric acid, a black precipitate of the subsulphide of mercury, Hg_2S.

With hydrochloric acid, a white precipitate of the chloride of mercury or calomel, $HgCl$, which turns black on the addition of ammonia.

With potass, a black precipitate of the hydrated suboxide, Hg_2O,H_2O, or $Hg_2H_2O_2$.

With ammonia, a black precipitate.

The solution placed on bright copper gives a silver stain.

1031. A solution of corrosive sublimate, $HgCl_2$, gives:

On the addition of hydrosulphuric acid, drop by drop, a white precipitate, which changes to yellow, then to brown, and finally becomes the black sulphide of mercury, HgS.

Caustic potass gives a yellow precipitate of the hydrated red oxide, HgO,H_2O, or HgH_2O_2.

Ammonia gives a white precipitate of the double amidide and chloride of mercury, $HgCl_2 + Hg2NH_2$.

Chloride of tin gives a white precipitate, which changes to gray, and consists of metallic mercury.

Bright copper introduced into the solution is silvered.

Bismuth.

Combining weight, 210; *symbol*, Bi.

1032. Bismuth generally occurs in the native state, and requires merely to be fused in a crucible to separate it from rock particles. It is a crystalline, brittle metal, white, with a shade of red, and has a density of 9·79; fuses at 507°, and volatilises at a strong heat. At ordinary temperature it is slowly oxidised, but when heated, it rapidly burns.

1033. When acted upon by nitric acid, the bismuth dissolves therein, forming the ternitrate of bismuth, $Bi3NO_3 + 5H_2O$ [old symbol, $BiO_3,3NO_5 + 10HO$], which, when thrown into water, gives a white precipitate of the subnitrate or *pearl white*, $2BiNO_4 + H_2O$ [old symbol, $5BiO_3,4NO_5 + 9HO$], which was used as a cosmetic. Salts of bismuth are recognised by a black precipitate of the sulphide Bi_2S_3 [old symbol, BiS_3], with hydrosulphuric acid, and a white precipitate with water, insoluble in tartaric acid.

Cadmium.

Combining weight, 112; *symbol*, Cd.

[*Old combining weight*, 56; *symbol*, Cd.]

1034. Cadmium occurs naturally as the sulphide of cadmium in the majority of zinc ores, and during the distillation of metallic zinc, the cadmium volatilises with the first portions.

1035. When free from zinc, it is a white metal, malleable and ductile, fuses at 442°, and has the specific gravity 8·7. It forms salts, which are characterised by giving a yellow precipitate with hydrosulphuric acid, insoluble in ammonia.

III. METALS WHICH GIVE NO PRECIPITATE WITH HYDROSULPHURIC ACID IN ALKALINE SOLUTIONS—GOLD, PLATINUM, ANTIMONY, TIN, AND ARSENIC.

Gold.

Combining weight, 197; *symbol*, Au (Aurum).

1036. Gold is probably the most widely diffused of the metals. It is found in every country, and always in the metallic state, often beautifully crystallised.

1037. The gold-dust of commerce consists of small particles of the metal, which have been washed by streams from their original position in the veins of rocks, and which are diffused through the sands at the bottom of the rivers fed by such streams. By taking advantage of the difference in specific gravity between the gold and the sand, the latter is washed away, and the gold-dust left.

1038. Gold is a bright-yellow metal, very malleable and ductile, and has the specific gravity of 19·34. It fuses at 2016° F. It does not tarnish in air or water, either by oxidation, or from the action of hydrosulphuric acid, and it resists the solvent action of all the ordinary acids. A mixture of nitric and hydrochloric acids (*aqua regia*) dissolves it, and yields a solution of the perchloride of gold, $AuCl_3$.

1039. The only important salt of gold is this perchloride, $AuCl_3$. It may be prepared by solution in the way just mentioned, but more conveniently on the small scale, by suspending gold-leaf in water, and sending a current of chlorine through the liquid. The gold rapidly dissolves, and yields at once a solution without excess of acid.

1040. If the solution be evaporated, it will yield crystals of the chloride of gold, which are very deliquescent, soluble in water, alcohol, and ether, and readily decomposed by heat and light. It stains the skin or other organic tissues purple, if they are wetted with its solution, and exposed to light.

1041. When this chloride is cautiously heated, it loses two-thirds of its chlorine, and leaves a subchloride, AuCl. There are also oxides of gold as well as bromides, iodides, sulphides, &c.

1042. *Tests for Gold.*—To one portion of the perchloride of gold a fresh solution of the protosulphate of iron is added. It immediately produces a precipitate of metallic gold, which remains long suspended in the liquid, and appears brown when looked at by reflected light, but bluish-green when the glass containing it is looked through so as to see it by transmitted light. If it be collected on a filter, dried, and rubbed with any smooth body, it will exhibit the characteristic yellow colour and lustre of gold.

1043. To a second portion of the perchloride, largely diluted with water, a few drops of solution of chloride of tin are added. It produces a purple precipitate, which has long gone by the name of *purple of Cassius*, and which consists of the double stannate of gold and tin, $Au_2SnO_3 + SnSnO_3 + 4H_2O$ [old symbol, $AuO,SnO_2 + SnO,SnO_2 + 4HO$].

Platinum.

Combining weight, 197; *symbol*, Pt.

[*Old combining weight*, 98·5; *symbol*, Pt.]

1044. Platinum, or, as it was originally named by the Spanish Americans, platina, in allusion to its silvery lustre—from the Spanish, *plata*, silver—is comparatively a rare metal, found in South America, Russia, and Ceylon, associated with palladium, rhodium, ruthenium, iridium, osmium, and a little iron. It is extracted from this alloy by a complicated process.

1045. The specific gravity of this metal is as high as 21·5. It is infusible, except before the oxyhydrogen blowpipe. It is, however, very malleable and ductile, so that it can be wrought comparatively easily into vessels. It is not tarnished or corroded by air, whether moist or dry. The ordinary acids, and the immense majority of chemical reagents, have likewise no action upon it. Aqua regia alone dissolves it, and caustic potass oxidises it, if fused upon it. It is a metal, accordingly, of the greatest value to the chemist, from its twofold power of resisting high temperatures and chemical action. Crucibles made of it are constantly in use in the performance of analysis (see fig. 60); and although it is some five times more costly than silver, large vessels of platinum are employed in the concentration of oil of vitriol.


Fig. 60.

1046. The only important salt of platinum is the perchloride, $PtCl_4$. It is prepared by dissolving the metal in nitrohydrochloric acid (aqua regia), evaporating to dryness, and dissolving the residue in water.

1047. This salt, it will be remembered, enabled us to distinguish the alkalis from each other, and was also a test for salts of hydriodic acid. (See pars. 626, 726, and 789.)

1048. A salt of platinum, such as the chloride in question, is readily recognised by its giving, with chloride of ammonium, a yellow precipitate, which, when heated to redness, leaves the metal in the state of black powder. In this state it is called spongy platinum. It can be obtained in a state of still finer division, when it is called *platinum-black.* This is procured by adding sugar and an excess of carbonate of sodium to solution of the perchloride of platinum. The liquid is then slowly raised to 212°, with occasional shaking. The metal separates as a black powder, which is washed, and dried. Chloride of tin gives with a solution of platinum a red precipitate or solution of the double stannate of platinum and tin, $PtSnO_3 + SnSnO_3$ [old symbol, $PtO,SnO_2 + SnO,SnO_2$].

Tin.

Combining weight, 118; *symbol*, Sn (Stannum).

[*Old combining weight*, 59; *symbol*, Sn.]

1049. Tin occurs in nature chiefly in combination with oxygen, as tinstone, which, when pure, is the peroxide of the metal,

SnO_2; but it is generally associated with other metals, and with sulphur.

1050. Tin is, next to silver, the whitest of the metals. Its density is 7·3, and fuses at 442°. It is soft and malleable. A bar of it, when bent, produces a peculiar creaking or crackling sound. It tarnishes very slowly, and slightly by exposure to the air, and is little acted on by dilute acids or reagents. It is peculiarly suitable, accordingly, for cooking-vessels, in the construction of which it is much employed. Ordinary tin-plate is sheet-iron coated at the surface with tin. Copper also is frequently covered on one side with it.

1051. *Salts of Tin.*—The most interesting salts of tin are the chlorides. The lower or *bichloride*, $SnCl_2$, is prepared by dissolving tin in hot hydrochloric acid. It may be obtained in crystals, but is generally kept in solution. It is interesting as a test for mercury and for gold.

1052. The higher or *perchloride*, $SnCl_4$, is prepared by dissolving tin in aqua regia, or by passing chlorine gas through the protochloride. It is largely used in dyeing. Compounds of tin resemble those of alumina in their power to fix organic colours on textile tissues. Each of these chlorides, when precipitated by carbonate of potassium, yields an oxide, the carbonic acid escaping.

1053. The protoxide, SnO, is prepared from the lower chloride or bichloride, and is unimportant. The peroxide, SnO_2, may be prepared from the perchloride, or by treating metallic tin with strong nitric acid. It is white when hydrated, and pale yellow when anhydrous. In the latter state it is employed by jewellers in polishing, under the name of putty powder. It is also used to render glass white and opaque, as in the preparation of the enamel for the dials of watches.

1054. *Tests for Tin.*—A solution of the lower chloride of tin may be taken to represent a protosalt of the metal.

Hydrosulphuric acid, or sulphide of ammonia, produces in it a dark-brown precipitate of the sulphide of tin, SnS.

Potass gives a white precipitate of hydrated protoxide,

SnO,H_2O, or SnH_2O_2 [old symbol, SnO,HO], which is soluble in excess of the alkali.

Chloride of gold produces the purple of Cassius (par. 1043).

Corrosive sublimate, a gray precipitate (par. 1031).

1055. The perchloride, and other persalts of tin, give—

With hydrosulphuric acid, or sulphide of ammonium, a yellow precipitate of bisulphide of tin, SnS_2.

Potass gives a white precipitate of the hydrated peroxide, SnO_2,H_2O, or SnH_2O_3 [old symbol, SnO_2,HO], soluble in excess of alkali.

1056. Both series of salts of tin, when mixed with carbonate of sodium, and heated in the inner blowpipe flame, yield metallic tin, which is distinguished from other white metals by being converted into a white powder (peroxide of tin) when strong nitric acid is dropped upon it.

Antimony.

Combining weight, 122; *symbol,* Sb (Stibium).

1057. Antimony occurs in nature in combination with sulphur, as the persulphide of antimony, Sb_2S_3 [old symbol, SbS_3]. This sulphide, which is its only ore, yields the metal readily when heated with iron, which combines with the sulphur.

1058. Antimony is a brilliant metal, of a bluish-white colour, highly crystalline, and very brittle, so that it is easily powdered.

1059. Its specific gravity is 6·71. It does not oxidise at ordinary temperatures, but it is readily combustible when heated, burning into the oxide, Sb_2O_3 [old symbol, SbO_3].

1060. It forms with oxygen three oxides—oxide of antimony, Sb_2O_3 [old symbol, SbO_3]; antimonious acid, Sb_2O_4 [old symbol, SbO_4]; and antimonic acid, Sb_2O_5 [old symbol, SbO_5]. The first of these is prepared by the combustion of antimony, also by roasting the sulphide in a current of air. The oxide in this case is impure. The antimonic acid is obtained by acting on antimony by strong nitric acid.

1061. With acids the oxide of antimony forms salts, of which the most important is the tartrate of potassium and antimony (tartar emetic), which is prepared by boiling the oxide with a solution of cream of tartar. The liquid, on concentration, yields crystals, consisting of potass, oxide of antimony, and tartaric acid;—in symbols:

$$KSbC_4H_4O_7 \text{ [old symbol, } KO,SbO_3,C_8H_4O_{10}].$$

1062. *Chloride.*—The chloride of antimony, $SbCl_3$, is prepared by dissolving the sulphide of antimony, Sb_2S_3, in hot hydrochloric acid, when hydrosulphuric acid, H_2S, is evolved, and chloride of antimony, $SbCl_3$, is left in the vessel. The anhydrous salt is volatile, highly corrosive, and very deliquescent. When the solution is dropped into water, a white precipitate appears, consisting of chloride and oxide (oxychloride) of antimony, $SbCl_3 + Sb_2O_3$ [old symbol, $SbCl_3 + 2SbO_3$].

1063. *Sulphide.*—The sulphide of antimony, as it occurs native, is a dark-gray crystalline solid, but as obtained by the precipitation of tartar emetic by hydrosulphuric acid, it is of an orange colour, and it may be deprived of water without losing this tint; but if strongly heated, it becomes black, without any change in composition.

1064. *Tests for Antimony.*—To observe these, a solution of tartar emetic should be taken.

To one portion, hydrosulphuric acid is added. It produces an orange-red precipitate of sulphide, Sb_2S_3 [old symbol, SbS_3]; the only sulphide of this colour. The precipitate is collected on a filter, washed, and gently dried. It is then transferred to a test-tube, and a few drops of hydrochloric acid added. Hydrosulphuric acid is given off, and terchloride of antimony, $SbCl_3$, formed. If the liquid be poured into water, a white precipitate appears, $SbCl_3 + Sb_2O_3$ [old symbol, $SbCl_3 + 2SbO_3$]. These tests are sufficient to characterise a soluble salt of antimony.

1065. Another method of identifying the salts of this metal is to add zinc and sulphuric acid to their solution. The hydrogen gas which is given off, separates the antimony, and in part combines with it, forming a gaseous compound, the antimoniuretted hydrogen, SbH_3, whilst in other part it separates as a black precipitate of metallic antimony, Sb. If the gas be set fire to whilst issuing from a glass jet, or if the gas be made to pass along a narrow glass tube placed horizontally, and heated red-hot by a spirit-lamp, the antimony will be deposited as a thin metallic coating. (See fig. 65, par. 1080.)

1066. A second process is to heat the salt of antimony (such as dry tartar emetic), mixed with carbonate of sodium, on charcoal in the inner flame of the blowpipe. Globules of the metal will easily be obtained. That the metal obtained by both methods is antimony, may be proved by dissolving it in hot hydrochloric acid, and observing the white precipitate which the chloride gives with water, and the orange precipitate with hydrosulphuric acid.

Arsenic.

Combining weight, 75; *symbol*, As.

1067. Arsenic is a steel-gray metal, having a brilliant lustre when first obtained, but soon losing its splendour if exposed to the air. It is nearly six times (5·9) heavier than water.

1068. It is not known in the liquid form, for when its crystals are heated, they change directly into a colourless gas, and condense again into crystals, provided air be excluded. If exposed to the air when raised in temperature, it combines with its oxygen, forming arsenious acid, As_2O_3 [old symbol, AsO_3]; and when this is heated with nitric acid, a second oxide is formed, called arsenic acid, As_2O_5 [old symbol, AsO_5].

1069. There are corresponding sulphides, and there are other salts, such as chlorides, all highly poisonous. To avoid repetition, we shall include the description of the more interesting of these in the statement of the processes by which the most important arsenical compounds—namely, arsenious acid—is detected.

1070. In trying the following experiments, great care must be taken to avoid tasting or inhaling the vapours of any of the arsenical compounds. All papers containing arsenic in any form, or bottles containing its solutions, should be carefully labelled, and kept out of the way of children and servants.

1071. *Arsenious Acid*, with which we begin, is known also by the names *white oxide of arsenic*, *white arsenic*, and simply *arsenic*, which last term the chemist applies only to the metal. Arsenious acid consists of two atoms of the metal and three of oxygen, As_2O_3. It is sold in the shops as a powder, which is white, heavy, and gritty. With it the following experiments may be tried:

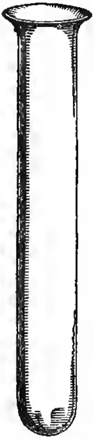


Fig. 61.

1072. As much of the arsenious acid as will lie on the tip of a penknife blade is placed at the bottom of a dry, wide test-tube (fig. 61), and slowly heated by a small spirit-lamp held at the shut end. The arsenious acid changes into a colourless, inodorous vapour, and ascending in the tube, condenses in small, regular crystals, which are quite unlike those of any other white sublimate. They are distinguished by their great brilliancy and play of colours, which rival those of the diamond, and likewise by their shape, which, when perfect, is that of the regular octahedron. Entire crystals can seldom be seen, but if the sublimate be examined with a magnifying glass, equilateral triangular faces may readily be observed; and this is enough, for no crystals except regular octahedrons possess faces bounded by equilateral triangles.

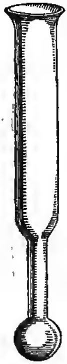


Fig. 62.

1073. A second portion of the arsenious acid is mixed with dry charcoal powder and anhydrous carbonate of sodium, or with cyanide of potassium and carbonate of sodium, and placed in the bulb of a Berzelius' tube (fig. 62). The mixture is introduced on a small slip of paper, so as not to soil the sides. The tube is then very gently moved backwards and forwards over a spirit-lamp, so as to expel moisture, and the drops of water which collect are wiped away by a roll of blotting-paper. The bulb is now heated to redness, when the metallic arsenic, deprived of its oxygen by the charcoal, or cyanide of potassium, rises in vapour, and condenses in the narrow neck above the bulb. Here it forms a brilliant ring of a dark-gray colour as seen through the glass, but on its inner surface of a lighter tint, and rough from the projection of crystalline points.

1074. The narrow neck of the Berzelius' tube, containing the ring of arsenic, is cut off by a file, and introduced into a narrow test-tube (fig. 63), which is then heated over a spirit-lamp. The small tube rapidly becomes empty and transparent, as the arsenic rises out of it in vapour, and meeting with abundance of air, combines with its oxygen to form arsenious acid, which condenses in its characteristic brilliant octahedral crystals in the cool part of the test-tube.

1075. A third portion of arsenious acid (commonly called *arsenic*) is boiled for some time with water, and the liquid is then filtered. It is a saturated solution of arsenious acid. Three test-glasses are half filled with this solution. 1. To the first, hydrosulphuric acid (accompanied by hydrochloric acid) is added. It produces a bright-yellow precipitate of sulphide of arsenic, As_2S_3 [old symbol, AsS_3]. This body is also called orpiment, and is the basis of the pigment called king's yellow, which is frequently used to poison flies, but is too deadly a substance to make its employment advisable for this purpose in places where children can have access to it. 2. To the second glass a solution of nitrate of silver, which has been mixed with a little ammonia, is added. It produces a primrose-yellow precipitate of the arsenite of the oxide of silver, Ag_3AsO_3. 3. To the third glass a solution of sulphate of copper, with which a little ammonia has been mixed, is added. It produces a bright green precipitate of the arsenite of copper, $CuHAsO_3$, known also as Scheele's green.

1076. These tests are amply sufficient for the identification of arsenious acid, when it is obtained in the state of a powder, or dissolved in a colourless liquid; but in coloured solutions, such as tea, coffee, or porter, the liquid tests would be of no value. Reinsch's process may be adopted for such liquids, and is also applicable to colourless solutions. To illustrate its application, solution of arsenious acid may be added to coffee or porter.

The liquid is then transferred to a flask, and a little hydrochloric acid, and some small pieces of copper-wire, or copper leaf, or thin sheet copper, added to it. The contents of the flask are then raised to the boiling-point, and kept at this temperature for some time. The copper separates the arsenic in the metallic form, and combines with it, becoming at the same time of a steel or dark-gray colour. This effect may be best observed with a colourless solution of arsenious acid.

1077. The pieces of blackened copper are removed from the flask, washed with a little water, and gently dried. They are then introduced into a narrow test-tube (fig. 63), and very gently heated, when the metallic arsenic, As, volatilises from the surface of the copper, and meeting with the oxygen of the air, it combines therewith, forming arsenious acid, As_2O_3. The latter deposits itself in the upper and cooler part of the tube, in the form of a ring of minute glistening crystals. A little water may then be boiled in the tube, and heat applied till the crystals dissolve, and the solution divided into three portions, tested with hydrochloric acid and hydrosulphuric acid, the ammoniated nitrate of silver, and the ammoniated sulphate of copper (par. 1075).

Fig. 63.

1078. Arsenic forms a compound with hydrogen, called arseniuretted hydrogen, AsH_3. It is the most poisonous of all the compounds of arsenic, and has already occasioned the death of several chemists who were experimenting with it. It must therefore be prepared and examined cautiously. To obtain it, zinc and sulphuric acid are added to an aqueous solution of arsenious acid contained in a bottle, with a glass jet passed through a cork which fits its neck. Fig. 64 represents an apparatus sold for the preparation of arseniuretted hydrogen. A piece of zinc is placed at the bend, and the acidulated solution of arsenious acid poured

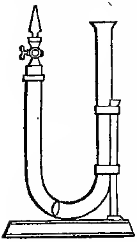


Fig. 64.

in. The stopcock is kept open till the air is chased out, and then closed. The gas accumulates in the shorter limb of the siphon, and forces the liquid past the zinc into the longer tube. In this way evolution of gas ceases when the liquid and zinc are separated from each other. When the stopcock is opened, the liquid returns from the long limb, and reproduces gas, forcing out what had accumulated. The hydrogen combines with the oxygen of the arsenious acid, producing water, and thereafter with the metal, to form the gas in question.

$$12H + As_2O_3 = 3H_2O \text{ and } 2AsH_3.$$

1079. The arseniuretted hydrogen burns with a grayish-white flame, producing a thick white smoke, which is arsenious acid; but if a cold body, such as a piece of porcelain, be pressed down upon a burning jet of the gas, the metal itself is deposited in a thin film. This experiment should be tried either in the open air, or with the bottle from which the gas is issuing standing on the hob of a grate.

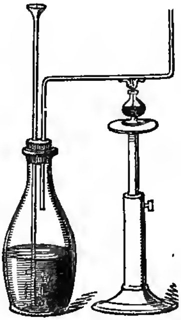


Fig. 65.

1080. By this method of treatment, complex liquids are frequently examined, and the process is called Marsh's. The most convenient form of apparatus is a gas bottle with funnel-tube, and a second or delivery tube bent at right angles (fig. 65). The latter tube must be made of German glass. Pure zinc and sulphuric acid are added to the liquid, containing the arsenical liquid, and the gas which is evolved is passed through the glass tube heated by a spirit-lamp. This occasions the separation of metallic arsenic (if it be present), which condenses in the tube a little in front of the flame. It is proved to be arsenic by the tests already given.

1081. The process for detecting arsenic by means of copper and hydrochloric acid is called Reinsch's test or process. That by means of zinc and sulphuric acid is named Marsh's process.

Another process, applicable to complex liquids, consists in passing hydrosulphuric acid through them as long as it occasions a precipitate of sulphide of arsenic, and then heating this with cyanide of potassium and carbonate of sodium by Berzelius's method, in the way arsenious acid is directed to be treated (par. 1073). This process is even applicable to coloured liquids, such as coffee or porter, where the colour of the sulphide cannot be seen, but it is not superior to Reinsch's or Marsh's processes.

1082. *Arsenic Acid*, As_2O_5 [old symbol, AsO_5].—It is prepared by heating arsenious acid with strong nitric acid, and evaporating to dryness to expel the excess of nitric acid. It is soluble in water, and gives a reddish-brown precipitate with nitrate of silver, which is highly characteristic. Films of metallic arsenic are sometimes identified by heating them with nitric acid, which converts them into arsenic acid, easily recognised by the reddish-brown precipitate of arseniate of silver, Ag_3AsO_4 [old symbol, $3AgO,AsO_5$], which it gives when added to a solution of nitrate of silver.

1083. The remaining metals are rare substances, which are in many instances mere chemical curiosities, though some of their compounds may be occasionally employed in the arts and manufactures.

1084. THALLIUM, Th; combining weight, 204; specific gravity, 11·9; is a metal somewhat similar to lead in its physical properties, and discovered by Crookes in 1861. It is found in seleniferous deposits in the sulphuric acid lead chambers, and forms a large number of salts. The metal and its salts, especially the chloride, impart a magnificent green colour to flame.

1085. INDIUM, In; combining weight, 71·8; is a metal found in certain zinc ores, especially in the Freiberg zinc blende. It was discovered by spectrum analysis, and communicates a very fine blue colour to flame. It forms a complete series of salts.

1086. URANIUM, U; combining weight, 120; specific gravity, 18·4; is a metal allied to iron and manganese in its chemical relations, and which is found in the mineral *pitchblende* (composed of nearly 80 per cent. of the black oxide of uranium, $2UO,U_2O_3$), and *uranite*, a hydrated double phosphate of calcium and uranium, $CaO,2U_2O_3,P_2O_5 + 8Aq$. It is a metal of a steel-white colour, and forms a series of compounds. The black oxide, $2UO,U_2O_3$, is valued for colouring porcelain of a deep pure black, and the sesquioxide, U_2O_3, is employed in the colouring of glass of a peculiar and beautiful yellow tint.

1087. NIOBIUM, or COLUMBIUM, Nb; combining weight, 97·5; is found in the mineral *tantalite*, occurring at Bodenmais, in Bavaria.

1088. TITANIUM, Ti; combining weight, 50; is present in the minerals *rutile*, *brookite*, and *anatase;* and in the slag from iron-smelting furnaces it is present in red glistening crystals of the cyanide and nitride of titanium.

1089. TANTALUM (columbium), Ta; combining weight, 137·6; is found in the minerals *tantalite* and *yttro-tantalite.*

1090. TUNGSTEN (wolfram), W; combining weight, 184; occurs in the mineral *wolfram*, and as a tungstate of calcium.

1091. MOLYBDENUM, Mo; combining weight, 96; is found as the bisulphide, MoS_2, in Bohemia and Sweden. The molybdate of ammonia, $2(NH_4)MoO_4$ [old symbol, NH_4O,MoO_3], is employed by the chemist in testing for phosphoric acid (acidulated with nitric acid), and which, on the application of heat, gives a characteristic yellow precipitate or solution.

1092. VANADIUM, V; combining weight, 137·2; is found native as the *vanadate of lead*, and also in certain ores of iron, and slags from iron furnaces.

1093. TELLURIUM, Te; combining weight, 129; is present in certain minerals, along with the metals gold, silver, copper, lead, and bismuth, and the simple substance possesses a high metallic lustre. By some chemists it is regarded as a non-metal, allied to sulphur and selenium, but there are strong reasons for considering that tellurium is a metal, as it possesses properties somewhat similar to those of bismuth, antimony, and arsenic.

1094. PALLADIUM, Pd; combining weight, 106·6; specific gravity, 11·4 to 11·8.

RHODIUM, R; combining weight, 104·4; specific gravity, 12·1.

RUTHENIUM, Ru; combining weight, 104·4; specific gravity, 11 to 11·4.

OSMIUM, Os; combining weight, 199·2; specific gravity, 21·4.

IRIDIUM, Ir; combining weight, 198; specific gravity, 21·15.

The above five metals are found associated with platinum in its native state, and in chemical properties they closely resemble that metal.

ATOMICITY OF THE ELEMENTS.

1095. We have now reached a point in the study of Chemistry when we can enter a little more fully on the consideration of the atom-combining power of the elementary substances, and the proportions in which each element may be regarded as equivalent to other elements. This department of the science has received much attention of late, and endeavours have been made to give a precision to the meaning of the terms employed, such as *atom*, *molecule*, *equivalent*, as well as *combining proportion*, which a few years ago were not considered as essentially different, and indeed were often used synonymously.

1096. The term *atom* is applied to the smallest quantity of any substance, simple or compound, which has the power of combining with an atom or atoms of the same or of any other substance, but which cannot exist in such proportion in a separate form. The atoms may be simple, as in the case of the elementary substances, or they may be compound, as in water, potass, or sulphuric acid. Thus, the atom of hydrogen is generally represented as 1, the atom of oxygen 16, the atom of silver 108, and the atom of gold 197.

1097. The atom of a compound substance is the sum of the weights of its components; thus, water, which is represented by the symbol H_2O, and is composed of two atoms of hydrogen, each of the power of 1, and one atom of oxygen of the power of 16, has the combined or compound atom H_2O, which really weighs 18. Again, sulphuric acid, H_2SO_4, contains two atoms of hydrogen (each 1), one atom of sulphur (32), and four atoms of oxygen (each 16), making in all 98 as the relative weight of the atom of sulphuric acid.

1098. In order to give a definite name to the proportions in which the atoms of the various substances unite together, the terms of *atomic weight* and *combining weight* or *combining proportion* are employed. These phrases may be used indifferently, the one for the other, and the quantity represented thereby is merely the smallest amount of the substance, either simple or compound, which can unite with one or more other substances.

1099. The atom is not regarded as capable of existing in a separate form, and wherever the substance is spoken of as uncombined, as in the case of pure hydrogen, then two atoms of the same substance are considered to be linked together. Thus, whilst hydrogen may unite as one atom, H, with other substances, as chlorine, Cl, to form hydrochloric acid, HCl, yet hydrogen in a state of freedom always occurs as a double atom, HH, and this proportion is a *molecule* of hydrogen, and is the smallest amount which can exist in a separate state. In like manner, a *molecule* of oxygen is two atoms, OO, of nitrogen, NN, and of chlorine, ClCl. The *molecular weights* of these substances are therefore double the atomic weights.

1100. The relation between the atom and the molecule of an elementary substance may be well observed by reference to the law of gaseous volumes (par. 230), where the combining or atomic measures of hydrogen, oxygen, nitrogen, and chlorine are represented by a single volume or square, □; whilst in representing a molecule of either of these elements we would require two volumes or squares, □□. The *molecular volume* of compound bodies is also represented by two squares, □□.

1101. The term *equivalent* or *equivalent number* is applied to that proportion of a substance which will replace or combine with a given proportion of another substance. The atomic weight or combining proportion may be the same as the equivalent, but not necessarily so; indeed there are many exceptions.

Thus, the atom or 1 of hydrogen combines with the atom or 35·5 of chlorine, and forms hydrochloric acid, HCl, where the atom of each of its components is satisfied by the proportion of the other, and the element hydrogen as 1 is *equivalent* to the element chlorine as 35·5. Again, the hydrogen can be replaced by sodium, 23, which, combining with the chlorine 35·5, produces chloride of sodium (common salt), $NaCl$, where the 23 of sodium is equivalent to 35·5 of chlorine, and is also equivalent to the 1 of hydrogen. The chlorine may, in its turn, be replaced or substituted by iodine, forming the iodide of sodium, NaI, where the iodine, in the proportion of 127 parts, is combined with the 23 parts of sodium, and the 127 parts of iodine are simply equivalent to the 35·5 of chlorine. The elements which by single atoms are thus *equivalent* to each other are spoken of as *monads*.

1102. In many cases, however, the single atom of an element may be replaced by two or more atoms of another element, and the two or more atoms are merely equivalent to the single atom which they become the substitute of. Thus, whilst one atom or 23 of sodium combines with and is equivalent to one atom or 35·5 of chlorine, forming chloride of sodium, $NaCl$, one atom of calcium or 40 satisfies two atoms of chlorine or $35{\cdot}5 + 35{\cdot}5 = 71$, forming chloride of calcium, $CaCl_2$, and consequently the one atom of calcium has double the equivalent power of the atom of sodium. It requires two atoms of chloride of sodium, $NaCl,NaCl$, to yield the same amount of chlorine as is present in the one atom of chloride of calcium, $CaClCl$, or more simply $CaCl_2$.

1103. This property may be stated in another way. Starting with hydrochloric acid, HCl, and acting thereon with sodium, Na, we form chloride of sodium, $NaCl$, the atom of sodium being equivalent to the atom of chlorine which it unites with, and also equivalent to the atom of hydrogen which it displaces. But when the hydrochloric acid is acted upon by one atom of calcium, Ca, we require to start with two atoms of hydrochloric acid, HCl,HCl, and these yield both of the atoms of chlorine to the calcium, forming chloride of calcium, $CaCl_2$, and the two atoms of hydrogen, HH, escape. It is manifest that the one atom of calcium combines with, saturates, and is equivalent to two atoms of chlorine, and equally so that it replaces and is equivalent in combining power to the two atoms of hydrogen, which are dislodged during the experiment. One atom of calcium, therefore, is not merely equivalent to one atom of hydrogen, chlorine, or sodium, but it is equivalent to two atoms of either of these substances. To mark this double equivalent power, the calcium and the class of elements which it represents are styled *dyads*.

1104. Other elements possess the property of replacing three atoms, or combining proportions, of hydrogen, as in the case of bismuth or gold, where the one atom of the chloride of bismuth, $BiCl_3$, or one atom of the chloride of gold, $AuCl_3$, contains three atoms of chlorine, Cl,Cl,Cl, united with one atom of the metal bismuth, Bi, or of the metal gold, Au. The same amount of chlorine, Cl,Cl,Cl, would be united with three atoms of hydrogen, H,H,H, in three atoms of hydrochloric acid, HCl,HCl,HCl, or with three atoms of sodium, Na,Na,Na, in three atoms of chloride of sodium, NaCl,NaCl,NaCl; and consequently the one atom of bismuth and the one atom of gold are each equivalent to three atoms of chlorine, with which they combine, or of hydrogen, which they may replace or become the substitute of. The same class of elements may be represented by nitrogen, N, one atom of which combines with three atoms of hydrogen, H,H,H, to form gaseous ammonia, NH_3; and the same amount of hydrogen would satisfy and require three atoms of chlorine, Cl,Cl,Cl, in forming hydrochloric acid, HCl,HCl,HCl. The nitrogen, gold, and bismuth are representatives of the class of elements which have a triple saturating or equivalent power, and they are called *triads*.

1105. Another class of substances have the property of uniting with or replacing four atoms of a single equivalent element. Thus one atom of carbon, C, unites with four atoms of hydrogen, H,H,H,H, in forming the light carburetted hydrogen (marsh gas), CH_4, and it is apparent that the same amount of hydrogen, H,H,H,H, would be united with four atoms of chlorine, Cl,Cl,Cl,Cl, in forming hydrochloric acid, HCl,HCl,HCl,HCl. The one atom of carbon, therefore, is equivalent to four atoms of chlorine, which it can replace, and to four atoms of hydrogen, with which it unites, and the class of elements to which carbon belongs is that of the *tetrads.*

1106. The foregoing observations may be summed up in the following statement: One atom of a monad is equivalent to one atom of any other monad, and can replace or combine with such to form a chemical compound. One atom of a dyad can satisfy or become the substitute of two atoms of any monad. One atom of a triad is in like manner equivalent to three atoms of a monad, or one of a dyad and one of a monad. And one atom of a tetrad has the equivalent power of four atoms of a monad; two atoms of a dyad; or one of a triad and one of a monad. To signify the relative saturating powers of the elements, it has been suggested that a dash be attached to each of the symbols of the elements, so as to indicate the one, two, three, or four equivalent power. Thus the monads hydrogen, sodium, chlorine, and iodine are represented as H', Na', Cl', and I'; the dyads calcium, iron, sulphur, and oxygen are symbolically written Ca'', Fe'', S'', and O''; the triads gold, bismuth, nitrogen, and phosphorus, as Au''', Bi''', N''', and P'''; and the tetrads platinum, tin, carbon, and silicon, as Pt'''', Sn'''', C'''', and Si''''. These additions, however, to the ordinary symbols are apt to detract from the general symmetry of formulæ, and are scarcely to be commended as helps to the memory.

CLASSIFICATION OF SUBSTANCES ACCORDING TO ATOMICITY.

1107. The relative power of atomicity possessed by the various elementary substances can be taken as a convenient and scientific plan for the classification of the elements, both non-metallic and metallic. The MONADS or single equivalent elements, one atom or combining proportion of which can unite with or replace one atom or combining proportion of hydrogen, are classified as *Monatomic*, *Monhydric*, or *Uni-equivalent* (more shortly Univalent) elements, and the following table gives the names and symbols of the members of the group arranged alphabetically:

Monatomic or Uni-equivalent Elements, 12 in Number.

Bromine	Br	Hydrogen	H	Rubidium	Rb
Cæsium	Cs	Iodine	I	Silver	Ag
Chlorine	Cl	Lithium	Li	Sodium	Na
Fluorine	F	Potassium	K	Thallium	Tl

1108. The DYADS, or those elements, one atom or combining proportion of which is equivalent to two atoms of hydrogen, are named the *Diatomic*, *Dihydric*, or *Bi-equivalent* (Bivalent) elements, and they are classified in the following table:

Diatomic or Bi-equivalent Elements, 25 in Number.

Barium	Ba	Iron	Fe	Palladium	Pd
Cadmium	Cd	Lanthanum	La	Selenium	Se
Calcium	Ca	Lead	Pb	Strontium	Sr
Cerium	Ce	Magnesium	Mg	Sulphur	S
Chromium	Cr	Manganese	Mn	Tellurium	Te
Cobalt	Co	Mercury	Hg	Thorium	Th
Copper	Cu	Nickel	Ni	Uranium	U
Didymium	D	Oxygen	O	Zinc	Zn
Glucinum	G				

1109. The TRIADS, or triple equivalent elements, one atom of which can replace or unite with three atoms or combining weights of hydrogen, are classified as the *Triatomic*, *Trihydric*, or *Terequivalent* (Terivalent) elements, and they are as follows :

Triatomic or Terequivalent Elements, 9 in Number.

Aluminum	Al	Bismuth	Bi	Nitrogen	N
Antimony	Sb	Boron	B	Phosphorus	P
Arsenic	As	Gold	Au	Rhodium	R

1110. The TETRADS, or elements which have the quadruple equivalent power of hydrogen, and one atom or combining proportion of which can unite with or become the substitute of four atoms of hydrogen, are known as the *Tetratomic*, *Tetrahydric*, or *Quadrequivalent* (Quadrivalent) elements, and the following table gives the members of the group :

Tetratomic or Quadrequivalent Elements, 8 in Number.

Carbon	C	Silicon	Si	Titanium	Ti
Niobium	Nb	Tantalum	Ta	Zirconium	Zr
Platinum	Pt	Tin	Sn		

1111. The above classification of substances according to the power which they possess of combining with or of replacing one, two, three, or four atoms of hydrogen, may be carried out, not only in the atomic or combining weights, but also in reference to the combining volumes of many of the elements.

The atomic or combining measure of all the elementary substances which can be obtained as vapour or gas is the same as that of hydrogen (excepting in the case of arsenic and phosphorus); and a given volume of hydrogen and the other elements in a gaseous state, making allowance for difference in temperature, may be represented as containing one atom or combining weight of each. This has been more fully referred to in a previous part of this treatise, under the law of gaseous volumes (pars. 196—231), and it will suffice now merely to state that an atom of hydrogen or 1, taken as unity, will occupy a volume or measure, represented by a single square, □; an atom of chlorine, or 35·5, will be exactly enclosed in the same measure or square, □; an atom of oxygen, or 16, will only fill the same volume or square, □; an atom of nitrogen, or 14, will also occupy only one measure, □; and an atom of carbon (in vapour, theoretical) or 12 will likewise fill only the one volume or square, □.

1112. When one atomic or combining measure of chlorine, Cl, □, combines with one atomic or combining volume of hydrogen, H, □, it will be found, after cooling, that the two gases have neither expanded nor contracted in volume, and that the gaseous mixture of hydrochloric acid, HCl, remains as two volumes, □□. When the hydrochloric acid thus formed is decomposed by chemical processes, the two volumes are resolved into one volume of chlorine and one volume of hydrogen. The same remark applies to iodine, I, □, and hydrogen, H, □, forming hydriodic acid, HI, □□; and to bromine, Br, □, and hydrogen, H, □, producing hydrobromic acid, HBr, □□. These are examples of the *monohydric* group of elements.

1113. On the other hand, when the atomic or combining measure of oxygen, O, □, unites with hydrogen to produce water, it demands two volumes of the hydrogen, HH, □ □, and the *three* volumes of gas become only *two* of steam, H_2O, □□, and occupy only two squares instead of three, so that there is an apparent disappearance of one third of the whole gaseous mixture. And again, when the two volumes of steam,

□□, are separated into the elements oxygen and hydrogen, there are obtained one volume of oxygen, □, and two volumes of hydrogen, □□. Similar remarks apply to hydrosulphuric acid, H_2S; hydroselenic acid, H_2Se; caustic potash, KHO, where one of the atoms of hydrogen is replaced by potassium, &c. These are types of the *dihydric* class.

1114. Again, one combining volume of nitrogen, N, □, unites with three combining volumes of hydrogen, HHH, □□□, and the *four* volumes pass into *two* volumes of gaseous ammonia, NH_3, □□, and when the latter is decomposed, the two volumes, □□, are again resolved into one volume of nitrogen, □, and three volumes of hydrogen, □□□. The same remarks apply to phosphuretted hydrogen, PH_3; arseniuretted hydrogen, AsH_3, and anti-moniuretted hydrogen, SbH_3. These illustrations prove the existence of the *trihydric* class.

1115. And lastly, one atomic or combining measure of carbon, C, □ (vapour hypothetical), combines with four combining volumes of hydrogen, HHHH, □□□□, and the *five* volumes go to form only *two* volumes of light carburetted hydrogen, CH_4, □□. In this instance, there is a disappearance of three-fifths of the entire volume of the gaseous mixture. When the light carburetted hydrogen is decomposed, it is resolved once again into one volume of carbon vapour, □ (hypothetical), and four volumes of hydrogen, □□□□. Other examples of this group may be taken from siliciuretted hydrogen, SiH_4, and even from carbonic acid anhydride, CO_2, and bisulphide of carbon, CS_2. In the two latter cases the oxygen and sulphur being dyads, the two atoms of either are equivalent to and represent the place of four atoms of hydrogen. This group is known as the *tetrahydric* class.

1116. The remarks upon the above classes of substances, and the mode of their union by measure or volume to form compound substances, may be summed up in the following statement: One volume of chlorine is satisfied with *one* volume of hydrogen, and is the type of the *monohydric* class; one volume of oxygen demands *two* volumes of hydrogen, and represents the *dihydric* group; one volume of nitrogen calls for *three* volumes of hydrogen, and forms an example of the *trihydric* class; and one volume of carbon is not content till it receives *four* volumes of hydrogen, and is the type of the *tetrahydric* group of elements. In each case only *two* volumes of the compound are formed.

1117. The hydrogen may be absent from the compound, and its place supplied by an equivalent amount of another element. Thus the triad gold combines with *three* combining volumes of chlorine, and forms chloride of gold, $AuCl_3$, and rhodium in a similar way produces chloride of rhodium, RCl_3. In these cases, the platinum and rhodium occupy the position of three atomic volumes of hydrogen, and are united with three atomic volumes of another monad, chlorine. Again, the metals platinum and tin each combine with four atomic volumes of chlorine, forming perchloride of platinum, $PtCl_4$, and perchloride of tin, $SnCl_4$, and thus one atom of the platinum and tin are equivalent to four atoms of the hydrogen, and can combine with four atomic volumes of chlorine.

THEORY OF THE CONSTITUTION OF ACIDS, BASES, AND SALTS.

1118. The consideration of the plan upon which chemical compounds are constructed must always be a matter of difficulty. The exact proportions in which the elements unite together can be accurately determined by the balance and the graduated flask or tube; but when more than two atoms are brought together and form a chemical compound, the minuteness of the particles places a barrier to the examination of their mode of arrangement, and any theory of the constitution of such compounds must partake more or less of the nature of a hypothesis, when an attempt is made to explain the order of their union.

1119. Till recently, two classes of acids were supposed to exist—the *Hydracids* and the *Oxyacids.* The former were such compounds as hydrochloric acid, consisting of hydrogen and chlorine; hydriodic acid, containing hydrogen and iodine; hydrobromic acid, composed of hydrogen and bromine; and hydrofluoric acid, formed of hydrogen and fluorine. The constitution of these acids will be more easily observed from the following tabular statement, including the symbols:

Hydrochloric Acid	HCl
Hydriodic Acid	HI
Hydrobromic Acid	HBr
Hydrofluoric Acid	HF

1120. The simplicity of the composition of the above substances, all of which possess strong acid properties, hardly admits of a difference of opinion as to the arrangement of the atoms. Some chemists choose to throw the hydrogen to the end of the name and symbol, and say chlorhydric acid, ClH, &c.; but such is a mere question of order in the pronunciation and symbolisation of the acids, and does not alter the fact that the atom of hydrogen is directly united with the atom of chlorine, and that no other element or atom intervenes.

1121. The second class of acids were called the oxyacids; and an excellent example of this class is afforded us in sulphuric acid or oil of vitriol. This acid contains a substance which is capable of separation, called sulphuric anhydride (par. 493). It is composed of one atom of sulphur and three atoms of oxygen, and has the symbol SO_3. The sulphuric anhydride does not possess acid properties; but when water is brought in contact with it, combination takes place, and the water, H_2O, and sulphuric anhydride, SO_3, becoming united together, the compound exhibits acid properties. The older theory was, that the atom of water merely assisted the sulphuric acid, SO_3, as an oxyacid to exhibit its acid properties, and the compound being ordinary sulphuric acid, was represented as H_2O,SO_3 [old notation, HO,SO_3]. The atom of water was placed by itself, and the sulphuric anhydride was marked down by itself; but the two were regarded as linked together and forming the compound.

1122. The more modern method of representing the oxyacids, however, is to regard them as hydracids, similar in construction to hydrochloric acid, and containing one or more atoms of hydrogen in chemical union with a compound body occupying the place of the chlorine. Thus the sulphuric acid is spoken of as containing a compound called sulphatoxygen, or sulphion, SO_4, in union with two atoms of hydrogen, H_2, forming the symbol H_2SO_4. It will be apparent that the latter formula contains the same symbols and number thereof as the oxyacid symbol, H_2O,SO_3, does. The difference is brought about by merely throwing all the atoms of oxygen together, and putting no comma or break, so that the substance may be regarded as a whole for the time being. It is not necessary to assume the actual existence of sulphatoxygen, SO_4, in the acid, or to deny its existence because it has never been isolated. It is best to regard all the elements, whether of the water, H_2O, or of the sulphuric anhydride, SO_3, to be so intimately united together in the sulphuric acid, H_2SO_4, that the components have practically ceased to have a separate existence.

1123. All the other acids formerly regarded as oxyacids may in a similar manner be shewn to be built up upon the hydracid type. Thus nitric anhydride, N_2O_5 (par. 330), possesses no acid properties; but when united with water, H_2O, it forms the very corrosive substance nitric acid, which might, on the principle of the construction of the oxyacids, be regarded as having the symbol H_2O,N_2O_5 [old notation, HO,NO_5]; but on the theory of the hydracids, may be written down as $H_2N_2O_6$, which is equal to two atoms of ordinary nitric acid, HNO_3, or a compound of one atom of hydrogen, H, and one atom of nitratoxygen, or nitration, NO_3. Similarly, phosphoric acid, containing phosphoric anhydride, P_2O_5 (par. 528), and three atoms of water, $3H_2O$, might be represented in symbols as an oxyacid, $3H_2O,P_2O_5$ [old notation, $3HO,PO_5$]; but on the theory of the hydracids, $3H_2,P_2O_8$, which is equal to two atoms of ordinary phosphoric acid, H_3PO_4.

1124. The fitness of the theory of hydracids to include all the so-called oxyacids may be best observed from the following table, where they are included in the same list as hydrochloric acid and other well-known hydracids: thus,

	Ingredients.	Symbols.
Hydrochloric Acid	H and Cl	= HCl
Hydriodic Acid	H and I	= HI
Hydrobromic Acid	H and Br	= HBr
Hydrofluoric Acid	H and F	= HF
Nitric Acid	H and NO_3	= HNO_3
Carbonic Acid	H_2 and CO_3	= H_2CO_3
Sulphuric Acid	H_2 and SO_4	= H_2SO_4
Phosphoric Acid	H_3 and PO_4	= H_3PO_4

1125. The acids, therefore, may all be regarded as hydracids; and it may be interesting and instructive to observe that there are certain classes of these acids. The first and simplest is observed in hydrochloric acid, where a molecule of hydrogen, HH, meeting with a molecule of chlorine, ClCl, gives rise to the formation of two atoms of hydrochloric acid, HCl,HCl. The second class is represented by nitric acid, which is constructed on the type of an atom of water, H_2O, with one of the atoms of hydrogen replaced by NO_2. Thus,

$$\left.\begin{matrix}H\\H\end{matrix}\right\} O + NO_2 = \left.\begin{matrix}H\\NO_2\end{matrix}\right\} O \text{ or } HNO_3 \text{ and } H.$$

1126. In like manner, the sulphuric acid is formed on the type of two atoms of water, $2H_2O$, with two of the atoms of the monad hydrogen replaced by one atom of the dyad, SO_2. Thus,

$$\begin{matrix}\left.\begin{matrix}H\\H\end{matrix}\right\} O\\\left.\begin{matrix}H\\H\end{matrix}\right\} O\end{matrix} + SO_2 = \left.\begin{matrix}H\\SO_2\\H\end{matrix}\right\} \begin{matrix}O\\O\end{matrix} \text{ or } H_2SO_4 \text{ and } H_2.$$

1127. And phosphoric acid is constructed on the type of three atoms of water, $3H_2O$, with three of the atoms of the monad hydrogen substituted by one atom of the triad phosphoric oxide PO. Thus,

$$\begin{matrix}\left.\begin{matrix}H\\H\end{matrix}\right\} O\\\left.\begin{matrix}H\\H\end{matrix}\right\} O\\\left.\begin{matrix}H\\H\end{matrix}\right\} O\end{matrix} + PO = \left.\begin{matrix}H\\H\\H\\PO\end{matrix}\right\} \begin{matrix}O\\O\\O\end{matrix} \text{ or } H_3PO_4 \text{ and } H_3.$$

1128. The acids, therefore, may be spoken of as compounds of hydrogen, and indeed they are strictly hydrogen *salts*, a term which will appear a little more clear when the discussion of salts is before us.

1129. The *bases* are a very numerous class of substances, and they are found in the organic as well as in the inorganic department of chemistry. The organic bases will be considered in the after-part of this treatise, and we have to discuss the inorganic bases at present. Every metal has the power of uniting with oxygen in one or more proportions, and thus forming bases. Thus, the metal calcium, Ca, when it combines with oxygen, O, forms the oxide of calcium (lime), CaO, which is a base. In a similar manner, sodium, Na, combines with oxygen, O, to form the base soda, Na_2O; and iron, Fe, in rusting, combines with the oxygen of the air, and forms the red oxide of iron (rust), Fe_2O_3, which is also a base.

1130. A base, therefore, may be constructed of a metal and oxygen, and in such circumstances a metal is known as a *basyle*, so that a base consists of a basyle, such as a metal and oxygen. Other substances than metals, however, may be basyles, and form bases, as in the case of ammonia, $2(NH_4)O$, which contains the compound basyle ammonium, NH_4, united with oxygen. The compound basyles act the part of simple basyles, or as the metals. The basyles may unite with sulphur in place of oxygen, and form bases; thus, sodium, Na, combining with sulphur, S, forms the base sulphide of sodium, Na_2S, analogous to the base oxide of sodium or soda, Na_2O. When sulphur combines with a basyle, the base which is formed is called a sulphur base to distinguish it from the ordinary or oxygen base.

1131. *Salts* are formed by the action of the acids upon metals, and by the union of the acids with bases. The simplest idea of a salt may be derived from chloride of sodium (common salt), NaCl, which may be obtained by acting upon hydrochloric acid, HCl, by sodium, Na, when the latter replaces the hydrogen, forming NaCl, whilst the atom of hydrogen escapes. Indeed, hydrochloric acid is a hydrogen salt, and in acting upon it by sodium and forming a metallic salt, we merely replace the hydrogen by the metal sodium. Thus, in symbols,

$$HCl + Na = NaCl \text{ and } H.$$

1132. When the hydrochloric acid is acted upon by a dyad metal, such as calcium, two atoms of the acid, 2HCl, are decomposed, and the one atom of the calcium, Ca, combines with the two of chlorine, Cl_2, to form the salt, the chloride of calcium, $CaCl_2$, whilst the two atoms of hydrogen escape. Thus,

$$2HCl + Ca = CaCl_2 \text{ and } H_2.$$

1133. In a similar manner, sulphuric acid, H_2SO_4, when it is brought in contact with certain metals, such as potassium, K, suffers decomposition, and the metal replaces the hydrogen, forming the salt, sulphate of potassium, K_2SO_4. Thus,

$$H_2SO_4 + K_2 = K_2SO_4 \text{ and } H_2.$$

1134. The whole of the hydrogen need not be removed from the acid, as where the potassium is not added in sufficient quantity to replace all the hydrogen, a salt is formed which differs from the preceding neutral salt in being an acid salt, and contains one of potassium and one of the hydrogen in combination with the sulphion, SO_4, forming the acid sulphate of potassium. Thus,

$$H_2SO_4 + K = KHSO_4 \text{ and } H.$$

1135. When a dyad metal, such as zinc, Zn, or iron, Fe, acts upon the sulphuric acid, H_2SO_4, one atom of the metal becomes the substitute of the two atoms of hydrogen, and the salt, sulphate of zinc, $ZnSO_4$, or sulphate of iron, $FeSO_4$, is formed. Thus,

$$H_2SO_4 + Zn = ZnSO_4 \text{ and } H_2$$
$$H_2SO_4 + Fe = FeSO_4 \text{ and } H_2.$$

1136. Salts are also formed by the action of the acids upon the oxides of metals and other bases. When two atoms of hydrochloric acid, 2HCl, are brought in contact with one atom of the oxide of magnesium or magnesia, MgO, the salt, chloride of magnesium, $MgCl_2$, is formed, and, at the same time, an atom of water, H_2O.

$$2HCl + MgO = MgCl_2 \text{ and } H_2O.$$

1137. In a similar way, sulphuric acid, H_2SO_4, and oxide of copper, CuO, form sulphate of copper (blue vitriol), $CuSO_4$, and an atom of water, H_2O, separates.

$$H_2SO_4 + CuO = CuSO_4 \text{ and } H_2O.$$

1138. And when hydrochloric acid is brought to bear upon the red oxide of iron, six atoms of the acid, $6HCl$, react upon one of the oxide of iron, Fe_2O_3, forming one of the perchloride of iron, Fe_2Cl_6, and three of water, $3H_2O$.

$$6HCl + Fe_2O_3 = Fe_2Cl_6 \text{ and } 3H_2O.$$

1139. These examples will exhibit well the general construction of salts, and will shew that the salts are merely hydracids, in which the hydrogen is replaced more or less completely by a metal. The following table will enable this connection to be more readily observed:

	Symbols.
Hydrochloric Acid, or the Chloride of Hydrogen	HCl
Chloride of Sodium	$NaCl$
Chloride of Calcium	$CaCl_2$
Chloride of Magnesium	$MgCl_2$
Perchloride of Iron	Fe_2Cl_6
Sulphuric Acid, or the Sulphate of Hydrogen	H_2SO_4
Neutral Sulphate of Potassium	K_2SO_4
Acid " "	$KHSO_4$
Sulphate of Zinc	$ZnSO_4$
Sulphate of Iron	$FeSO_4$
Sulphate of Copper	$CuSO_4$

1140. The above classification of salts is carried out on what is termed the *binary theory*, where all the acids are regarded as salts containing hydrogen in place of a metal, and all the salts containing metals are formed by the substitution of an equivalent amount of the metal for the hydrogen in the hydracid. The two parts of the salt are, on the one hand, the hydrogen or the metal, either of which is the *basyle;* and, on the other hand, the chlorine, sulphion, or similar substance, which is termed the *salt radicle.* A salt, therefore, is composed of a basyle and a salt radicle. The basyle may be a metal, hydrogen—which is probably the vapour of a very volatile metal—or a compound substance such as ammonium, NH_4, which plays the part of a simple substance. In organic chemistry there are many compound basyles. The salt radicle may be simple, as in chlorine, or compound, as in sulphion, and of the compound salt radicles we shall encounter a large number when we are considering Organic Chemistry. Certain salts are constructed of basyles and salt radicles which contain sulphur in place of oxygen; and these are known as sulpho-salts.

CRYSTALLISATION AND CRYSTALLOGRAPHY.

1141. A large number of substances, both simple and compound, are susceptible of existence as solids in regular geometrical forms which have generally plane surfaces, bounded by angles which are constant. These geometrical solids are termed *crystals*, and the process by which they are produced is called *crystallisation*. Crystallisation is generally determined by conferring fluidity upon the substance to be crystallised, so as to give its particles freedom of motion on each other, and then leaving the fluid undisturbed, so that the molecules may slowly return to the solid state.

1142. A crystallisable body is rendered fluid by heating it till—1, it melts into a liquid; or, 2, sublimes as a vapour; or, 3, it may be dissolved in a liquid which is afterwards caused to evaporate slowly. Some substances, such as sulphur, can be crystallised in all the three ways—that is, by fusion, vaporisation, or solution; the greater number of the metals chiefly by fusion, the majority of salts and crystallisable organic bodies by solution. It is also possible, by decomposing a compound liquid or gas, to obtain one or more of its constituents crystallised. The metals, for example, are readily crystallised by decomposing their solutions slowly by galvanic currents; and various compound gases, when passed through red-hot tubes, deposit certain of their constituents as crystals. Uncrystalline solids, also, such as malleable iron, in certain circumstances have a crystalline structure developed in them, without becoming in the slightest degree fluid.

1143. The same substance crystallises in a great variety of shapes; but when these are carefully examined, they are found to differ from each other only by slight modifications, so that in the majority of cases the crystalline forms of each single substance can be grouped together under one *crystallographic system*, as it is called, which includes a great variety of shapes, all of which a crystal exhibiting one of these forms may present; whilst, on the other hand, in the majority of cases it never occurs in any of the shapes belonging to a different system.

1144. Numerous as crystalline forms are, they may all be included under six systems. Each of these contains a number of related, but dissimilar shapes, which agree in containing the same crystalline axes, as they are called. These axes are three straight lines passing through the same point, and terminating in the surfaces or angles of the crystal. Thus the first system is called the *octohedral*, or *regular* system of crystallisation. The three axes are at right angles to each other, and equal in length. The cube or hexahedron, which is one of the forms of this system, consists of six planes or squares, so arranged, that each is perpendicular to one axis, and parallel to the other two. The axes in this form terminate in the centre of each of the six faces of the crystal, as the figure will shew. (See fig. 66, A.)

1145. In the octohedron, on the other hand, the axes terminate in the angles of the crystals, as the figure illustrates. (See fig. 66, B.)

1146. The other systems are named and characterised as follows: 2. The *square prismatic* has the axes at right angles to each other, but two only of them equal in length, the third being longer or shorter than the other two. 3. The *right prismatic* has the axes also at right angles, but all of different lengths. 4. The *rhombohedral* has the axes equal in length, and crossing at equal but not right angles. 5. The *oblique prismatic* has two of the axes intersecting each other obliquely, while the third is perpendicular to both, and unequal in length. 6. The *doubly-oblique prismatic* has all three axes intersecting each other obliquely, and unequal.

1147. The crystalline systems are best understood by connecting together wires, wooden rods, or pieces of stiff pasteboard, so as to represent the several axes, and then constructing around these some of the more common crystalline forms of each system. Rods of wood are most convenient, dovetailed into each other where they cross or intersect. Six of these will be requisite, if all the systems are to be illustrated, but fewer will suffice to make plain the scheme of crystalline systems.

1148. By passing white cords or threads across the ends of the several rods, so as to connect them together, each set of axes (except that of the rhombohedral system) becomes changed into one of the octohedrons of its system.

1149. Square-faced, rectangular, or rhombic forms, such as the cube, the different prisms, and the rhombohedron, may be represented by means of wires.

1150. The following figures represent two of the principal forms of four of the systems. The thick black lines correspond to the wooden rods or axes; the thin continuous lines are threads in the case of the octohedrons, and stout wires in the cube and prisms. The dotted lines in the figures of the latter are thin iron wires to receive and support the ends of the wooden rods. The same set of rods serves for two figures, A and B.

1151. Without an extensive series of models, specimens, and drawings, the various crystalline secondary or derivative forms cannot be understood. Two models in each system of the chief figures would suffice to give a general conception of the differences in shape characteristic of each system. The following substances will afford specimens:

1152. In the regular system the majority of the metals represent the characteristic figures, also the diamond, fluor-spar, iron-pyrites, alum, galena, the garnet, &c.

Fig. 66. Regular System.—A, skeleton cube. B, skeleton regular octohedron; all the faces being equilateral triangles.

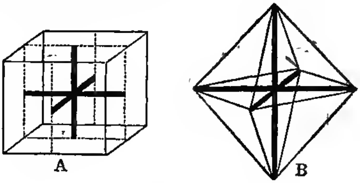


Fig. 66.

Fig. 67. Square Prismatic System.—A, a square prism. B, an octohedron with a square base; all the faces isosceles triangles.

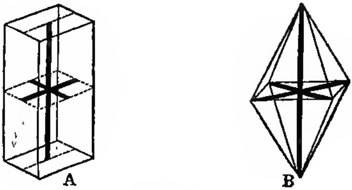


Fig. 67.

Fig. 68. Right Prismatic System.—A, right prism. B, an octohedron with a rhombic base; all the faces scalene triangles.

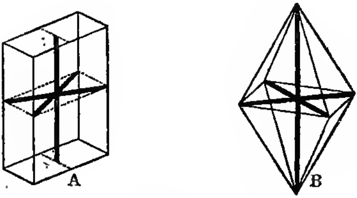


Fig. 68.

Fig. 69. Oblique Prismatic System.—A, oblique rhombic prism. B, octohedron of the same system.

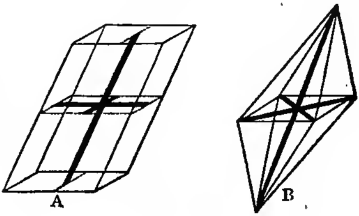


Fig. 69.

1153. To the square prismatic system belong tinstone and ferrocyanide of potassium. To the right prismatic system—sulphur, iodine, sulphate of potassium. To the oblique prismatic—carbonate and phosphate of sodium, borax, green vitriol. To the doubly-oblique prismatic system—sulphate of copper. To the rhombohedral system—calcareous spar, quartz, ice, arsenic, antimony.

1154. Some bodies present an exception to the otherwise general law, that the crystals of one substance belong all to a single crystallographic system. Thus carbon, as the diamond, is a regular octohedron, and a member, therefore, of the regular system; as graphite or plumbago, it is a six-sided prism, which belongs to the rhombohedral system.

1155. Sulphur, in like manner, crystallises when melted, in a shape belonging to the *oblique* prismatic system; when dissolved, in a shape belonging to the *right* prismatic system.

1156. Sulphur, carbon, and the other bodies which present this character, are said to be *dimorphous*, from two Greek words signifying *two-shaped.*

1157. Again, exactly the same shape is found to characterise different bodies, so that all the corresponding angles of these substances measure alike. Sulphate of magnesium and sulphate of zinc present this character, and cannot be distinguished by the eye from each other.

1158. Bodies which present this character are said to be *isomorphous*, a term signifying similiform, or possessed of the same shape. When substances are isomorphous, they frequently closely resemble each other in chemical properties.

1159. Percentage of Anhydrous Nitric Acid, or Nitric Anhydride in Samples of Nitric Acid.

Specific Gravity of Solution.	N_2O_5 in 100 parts by weight.	Specific Gravity of Solution.	N_2O_5 in 100 parts by weight.
1·5000	79·700	1·2887	39·053
1·4940	77·309	1·2705	36·662
1·4850	74·918	1·2523	34·271
1·4760	72·527	1·2341	31·880
1·4670	70·136	1·2148	29·489
1·4570	67·745	1·1958	27·098
1·4460	65·354	1·1770	24·707
1·4346	62·963	1·1587	22·316
1·4228	60·572	1·1403	19·925
1·4107	58·181	1·1227	17·534
1·3978	55·790	1·1051	15·143
1·3833	53·399	1·0878	12·752
1·3681	51·068	1·0708	10·361
1·3529	48·617	1·0540	7·970
1·3376	46·226	1·0375	5·579
1·3216	43·835	1·0212	3·188
1·3056	41·444	1·0053	0·797

1160. Percentage of Ammonia in Various Strengths of Solutions of Ammonia (at 57° F.).

Specific Gravity of Solution.	Ammonia in 100 parts by weight.	Specific Gravity of Solution.	Ammonia in 100 parts by weight.
0·8844	36	0·9314	18
0·8864	35	0·9347	17
0·8885	34	0·9380	16
0·8907	33	9414	15
0·8929	32	0·9449	14
0·8953	31	0·9484	13
0·8976	30	0·9520	12
0·9001	29	0·9556	11
0·9026	28	0·9593	10
0·9052	27	0·9631	9
0·9078	26	0·9670	8
0·9106	25	0·9709	7
0·9133	24	0·9749	6
0·9162	23	0·9790	5
0·9191	22	0·9831	4
0·9221	21	0·9873	3
0·9251	20	0·9915	2
0·9283	19	0·9959	1

1161. Percentage of Sulphuric Acid in Acid of Different Strengths (at 60°).

Specific Gravity of Solution.	Sulphuric Anhydride, SO_3, in 100 parts by weight.	Sulphuric Acid (Oil of Vitriol), H_2SO_4, in 100 parts by weight.	Specific Gravity of Solution.	Sulphuric Anhydride, SO_3, in 100 parts by weight.	Sulphuric Acid (Oil of Vitriol), H_2SO_4, in 100 parts by weight.
1·8460	81·54	100	1·3697	39·14	48
1·8415	79·90	98	1·3530	37·51	46
1·8366	78·28	96	1·3345	35·88	44
1·8288	76·65	94	1·3165	34·25	42
1·8181	75·02	92	1·2999	32·61	40
1·8070	73·39	90	1·2826	30·98	38
1·7901	71·75	88	1·2654	29·35	36
1·7728	70·12	86	1·2490	27·72	34
1·7540	68·49	84	1·2334	26·09	32
1·7315	66·86	82	1·2184	24·46	30
1·7080	65·23	80	1·2032	22·83	28
1·6860	63·60	78	1·1876	21·20	26
1·6624	61·97	76	1·1706	19·57	24
1·6415	60·34	74	1·1549	17·94	22
1·6204	58·71	72	1·1410	16·31	20
1·5975	57·08	70	1·1246	14·68	18
1·5760	55·45	68	1·1090	13·05	16
1·5503	53·82	66	1·0953	11·41	14
1·5280	52·18	64	1·0809	9·78	12
1·5066	50·55	62	1·0682	8·15	10
1·4860	48·92	60	1·0544	6·52	8
1·4660	47·29	58	1·0405	4·89	6
1·4460	45·66	56	1·0268	3·26	4
1·4265	44·03	54	1·0140	1·63	2
1·4073	42·40	52	1·0074	0·815	1
1·3884	40·77	[illegible]			

Definite Compounds of Sulphuric Anhydride and Water.

Hydrate.	Formula.	Fusing Point F.	Boiling Point F.	Specific Gravity.
		°	°	
Sulphuric anhydride...	SO_3	65	...	...
Dihydrate...............	H_2SO_4,SO_3	95	...	...
Oil of vitriol............	H_2SO_4	51	640	1·846
Glacial acid.............	H_2SO_4,H_2O	47	435	1·780
Graham's hydrate......	$H_2SO_4,2H_2O$	...	348	1·632

1162. Percentage of Hydrochloric Acid in Samples of Various Strengths.

Specific Gravity of Solution.	Hydrochloric Acid in 100 Parts by Weight.	Specific Gravity of Solution.	Hydrochloric Acid in 100 Parts by Weight.
1·21	42·43	1·10	20·20
1·20	40·40	1·09	18·18
1·19	38·38	1·08	16·16
1·18	36·36	1·07	14·14
1·17	34·34	1·06	12·12
1·16	32·32	1·05	10·10
1·15	30·30	1·04	8·08
1·14	28·28	1·03	6·06
1·13	26·26	1·02	4·04
1·12	24·24	1·01	2·02
1·11	22·22		

1163. Percentage of Anhydrous Potass in Various Strengths of Solutions of Potass.

Specific Gravity.	Anhydrous Potass, K_2O, in 100 Parts by Weight.	Specific Gravity.	Anhydrous Potass, K_2O, in 100 Parts by Weight.
1·60	46·7	1·33	26·3
1·52	42·9	1·28	23·4
1·47	39·6	1·23	19·5
1·44	36·8	1·19	16·2
1·42	34·4	1·15	13·0
1·39	32·4	1·11	9·5
1·36	29·4	1·06	4·7

1164. Percentage of Anhydrous Soda in Various Strengths of Solutions of Soda.

Specific Gravity of Solution.	Anhydrous Soda, Na_2O, in 100 Parts by Weight.	Specific Gravity of Solution.	Anhydrous Soda, Na_2O, in 100 Parts by Weight.
1·56	41·2	1·32	23·0
1·50	36·8	1·29	19·0
1·47	34·0	1·23	16·0
1·44	31·0	1·18	13·0
1·40	29·0	1·12	9·0
1·36	26·0	1·06	4·7

The Gases and Vapours.

1165. Order of Specific Gravity or Density.—Air = 1·000.

Hydrogen	0·0692
Light Carburetted Hydrogen	0·5576
Ammonia, Gaseous	0·590
Water Vapour	0·622
Carbonic Oxide	0·967
Nitrogen	0·972
Heavy Carburetted Hydrogen	0·978
Nitric Oxide	1·039
Oxygen	1·1056
Phosphuretted Hydrogen	1·185
Hydrosulphuric Acid (Sulphuretted Hydrogen)	1·191
Hydrochloric Acid, Gaseous	1·261
Nitrous Oxide	1·527
Carbonic Acid	1·529
Sulphur, Vapour	2·230
Sulphurous Acid	2·247
Chlorine	2·470
Phosphorus, Vapour	4·500
Bromine, Vapour	5·540
Mercury, Vapour	6·976
Iodine, Vapour	8·716
Arsenic, Vapour	10·600

The Metals.

1166. Order of Specific Gravity or Density.

Platinum	21·53
Osmium	21·4
Iridium	21·15
Gold	19·34
Uranium	18·4
Tungsten	17·6
Mercury	13·59
Rhodium	12·1
Thallium	11·91
Palladium	11·8
Ruthenium	11·4
Lead	11·36
Silver	10·53
Bismuth	9·79
Cobalt	8·95
Copper	8·95
Nickel	8·82
Molybdenum	8·62
Cadmium	8·69
Manganese	8·01
Iron	7·84
Tin	7·29
Zinc	7·14
Chromium	6·81
Antimony	6·71
Tellurium	6·25
Arsenic	5·96
Aluminum	2·56
Strontium	2·54
Glucinum	2·1
Magnesium	1·74
Calcium	1·57
Rubidium	1·52
Sodium	0·972
Potassium	0·865
Lithium	0·593

1167. Order of Fusibility or Melting Point.

Platinum	Only fusible before the oxyhydrogen blowpipe.	
Rhodium		
Iridium		
Vanadium		
Ruthenium		
Osmium		
Palladium	Not fusible in forge fire, but soften and agglomerate.	
Molybdenum		
Tungsten		
Chromium		
Malleable Iron	Fusible in highest heat of forge.	
Cobalt		
Nickel		
Manganese		
Cast Iron	2786°	Fahr.
Gold	2016°	„
Copper	1996°	„
Silver	1873°	„
Aluminum	Full red-heat.	
Calcium		
Antimony	1150°	Fahr.
Zinc	773°	„
Arsenic		„
Tellurium		„
Lead	617°	„
Thallium	561°	„
Bismuth	507°	„
Cadmium	442°	„
Tin	442°	„
Lithium	356°	„
Sodium	207°·7	„
Potassium	144°·5	„
Rubidium	101°·3	„
Mercury	− 39°	„

The Metals.

1168. Malleability.

When plates or bars of the metals are passed between heavy rollers, or are subjected to a process of hammering, they exhibit variable powers of retaining their cohesion, as the metal passes into the form of a thin sheet or leaf. Gold is the most malleable of all the metals, being capable of being beaten so thin, that the leaf is only $\frac{1}{280,000}$th of an inch in thickness, and a square foot only weighs 3 grains.

ORDER OF MALLEABILITY.

Most Malleable.

Gold.
Silver.
Copper.
Platinum.
Palladium.
Iron.
Aluminum.
Tin.
Zinc.
Lead.
Cadmium.
Nickel.
Cobalt.

Least Malleable.

1169. Ductility.

The property of being drawn into wire of greater or less fineness is exhibited by the metals. A single grain of gold can be drawn into a wire 500 feet in length, and the diameter of the thinnest platinum wire does not exceed $\frac{1}{30,000}$th of an inch. In drawing these fine wires of gold or platinum, the metals are covered with a cylinder of silver, and both are drawn together, and thereafter the outer silver coating is dissolved away by nitric acid.

ORDER OF DUCTILITY.

Most Ductile.

Gold.
Silver.
Platinum.
Iron.
Copper.
Palladium.
Cadmium.
Cobalt.
Nickel.
Aluminum.
Zinc.
Tin.
Lead.

Least Ductile.

1170. Tenacity.

The strength or cohesive power of the metals, which enables them to sustain greater or less weights, is spoken of as their tenacity. A bar or wire of the metal is securely suspended from a vice or other fixture, and weights are attached to the lower end till the wire parts or breaks. Iron possesses the greatest tenacity, and the following table gives the relative weights which several of the metals will suspend.

ORDER OF TENACITY.

Most Tenacious.

Iron	26
Copper	17
Palladium	15
Platinum	13
Silver	8·9
Zinc	8
Gold	5·6
Tin	1·3
Cadmium	1·2
Lead	1

Least Tenacious.

Relative Value of the French or Metrical with the Common British Measures.

1171. Table I.—Measures of Length.

	In British Inches.	In British Feet = 12 Inches.	In British Yards = 3 Feet.	In British Fathoms = 6 Feet.	In British Miles = 1760 Yards.
Millimetre	0·03937	0·0032809	0·0010936	0·0005468	0·0000006
Centimetre	0·39371	0·0328090	0·0109363	0·0054682	0·0000062
Decimetre	3·93708	0·3280899	0·1093633	0·0546816	0·0000621
Metre	39·37079	3·2808992	1·0936331	0·5468165	0·0006214
Decametre	393·70790	32·8089920	10·9363310	5·4681655	0·0062138
Hectometre	3937·07900	328·0899200	109·3633100	54·6816550	0·0621382
Kilometre	39370·79000	3280·8992000	1093·6331000	546·8165500	0·6213824
Myriometre	393707·90000	32808·9920000	10936·3310000	5468·1655000	6·2138244

1172. Table II.—Measures of Surface.

	In British Sq. Feet.	In British Sq. Yards = 9 Sq. Feet.	In British Poles = 272·25 Sq. Feet.	In British Roods = 10,890 Sq. Feet.	In British Acres = 43,560 Sq. Feet.
Centiare or sq. metre	10·7642993	1·1960333	0·0395383	0·000988457	0·0002471143
Are or 100 sq. metres	1076·4299342	119·6033260	3·9538290	0·098845724	0·0247114310
Hectare or 10,000 sq. metres	107642·9934183	11960·3326020	395·3828959	9·884572398	2·4711430996

1173. Table III.—Measures of Capacity.

	In Cubic Inches.	In Cubic Feet = 1728 Cubic Inches.	In Pints = 34·65923 Cubic Inches.	In Gallons = 8 Pints = 277·27384 Cubic Inches.	In Bushels = 8 Gallons = 2218·19075 Cubic Inches.
Millilitre, or cubic centimetre......	0·061027	0·0000353	0·001761	0·00022010	0·000027512
Centilitre, or 10 cubic centimetres.	0·610271	0·0003532	0·017608	0·00220097	0·000275121
Decilitre, or 100 cubic centimetres.	6·102705	0·0035317	0·176077	0·02200967	0·002751208
Litre, or cubic decimetre............	61·027052	0·0353166	1·760773	0·22009668	0·027512085
Decalitre, or centistere	610·270515	0·3531658	17·607734	2·20096677	0·275120846
Hectolitre, or decistere..............	6102·705152	3·5316581	176·077341	22·00966767	2·751208452
Kilolitre, or stere, or cubic metre..	61027·051519	35·3165807	1760·775314	220·09667675	27·512084594
Myriolitre, or decastere..............	610270·515194	353·1658074	17607·734140	2200·96676750	275·120845937

1174. Table IV.—Measures of Weight.

	In English Grains.	In Avoirdupois Ounces = 437·5 Grains.	In Avoirdupois Lbs. = 7000 Grains.	In Cwts. = 112 Lbs. = 784,000 Grains.	Tons = 20 Cwt. = 15,680,000 Grains.
Milligramme	0·015432	0·000035	0·0000022	0·00000002	0·000000001
Centigramme	0·154323	0·000353	0·0000220	0·00000020	0·000000010
Decigramme	1·543235	0·003527	0·0002205	0·00000197	0·000000098
Gramme	15·432349	0·035274	0·0022046	0·00001968	0·000000984
Decagramme..............................	154·323488	0·352739	0·0220462	0·00019684	0·000009842
Hectogramme............................	1543·234880	3·527394	0·2204621	0·00196841	0·000098421
Kilogramme..............................	15432·348800	35·273940	2·2046213	0·01968412	0·000984206
Myriogramme............................	154323·488000	352·739401	22·0462126	0·19684118	0·009842059

Table V.—Value of Principal British Weights and Measures.

1175. 1 British inch in length = 2·539954 centimetres.
1 〃 foot 〃 = 3·0479449 decimetres.
1 〃 yard 〃 = 0·91438348 metre.
1 〃 mile 〃 = 1·6093149 kilometre.

1176. 1 British square inch = 6·4513669 square centimetres.
1 〃 〃 foot = 9·2899683 〃 decimetres.
1 〃 〃 yard = 0·83609715 square metre or centiare.
1 〃 〃 acre = 0·404671021 hectare.

1177. 1 British cubic inch = 16·3861759 cubic centimetres.
1 〃 〃 foot = 28·3153119 〃 decimetres.
1 〃 gallon = 4·543457969 litres.

1178. 1 British grain = 0·064798950 gramme.
1 ounce avoirdupois = 28·349540625 〃
1 lb. avoirdupois = 0·453592650 kilogramme.
1 British cwt. = 50·802376800 〃

1179.

1 lb. avoirdupois	7000	grains.
1 〃 Troy	5760	〃
1 ounce avoirdupois	437·5	〃
1 〃 Troy	480	〃
1 drachm apothecaries	60	〃
1 〃 avoirdupois	27·344	〃

1180. Imperial gallon of water at 60° F. contains 70,000 grains.
〃 pint 〃 〃 〃 8,750 〃
The fluid ounce 〃 〃 〃 437·5 〃
imperial pint = 34·66 cubic inches.
20 fluid ounces = 1 imperial pint.
8 imperial pints = 1 imperial gallon.

Thermometric Equivalents.

1181. **Relation of the Thermometer Scales known as Centigrade and Fahrenheit.**

Centigrade, Cent. or C.	Fahrenheit, Fahr. or F.	Centigrade, Cent. or C.	Fahrenheit, Fahr. or F.	Centigrade, Cent. or C.	Fahrenheit, Fahr. or F.	Centigrade, Cent. or C.	Fahrenheit, Fahr. or F.
+ 100 =	+ 212	+ 64 =	+ 147·2	+ 29 =	+ 84·2	− 6 =	+ 21·2
99 =	210·2	63 =	145·4	28 =	82·4	7 =	19·4
98 =	208·4	62 =	143·6	27 =	80·6	8 =	17·6
97 =	206·6	61 =	141·8	26 =	78·8	9 =	15·8
96 =	204·8	60 =	140	25 =	77	10 =	14
95 =	203	59 =	138·2	24 =	75·2	11 =	12·2
94 =	201·2	58 =	136·4	23 =	73·4	12 =	10·4
93 =	199·4	57 =	134·6	22 =	71·6	13 =	8·6
92 =	197·6	56 =	132·8	21 =	69·8	14 =	6·8
91 =	195·8	55 =	131	20 =	68	15 =	5
90 =	194	54 =	129·2	19 =	66·2	16 =	3·2
89 =	192·2	53 =	127·4	18 =	64·4	17 =	1·4
88 =	190·4	52 =	125·6	17 =	62·6	18 =	− 0·4
87 =	188·6	51 =	123·8	16 =	60·8	19 =	2·2
86 =	186·8	50 =	122	15 =	59	20 =	4
85 =	185	49 =	120·2	14 =	57·2	21 =	5·8
84 =	183·2	48 =	118·4	13 =	55·4	22 =	7·6
83 =	181·4	47 =	116·6	12 =	53·6	23 =	9·4
82 =	179·6	46 =	114·8	11 =	51·8	24 =	11·2
81 =	177·8	45 =	113	10 =	50	25 =	13
80 =	176	44 =	111·2	9 =	48·2	26 =	14·8
79 =	174·2	43 =	109·4	8 =	46·4	27 =	16·6
78 =	172·4	42 =	107·6	7 =	44·6	28 =	18·4
77 =	170·6	41 =	105·8	6 =	42·8	29 =	20·2
76 =	168·8	40 =	104	5 =	41	30 =	22
75 =	167	39 =	102·2	4 =	39·2	31 =	23·8
74 =	165·2	38 =	100·4	3 =	37·4	32 =	25·6
73 =	163·4	37 =	98·6	2 =	35·6	33 =	27·4
72 =	161·6	36 =	96·8	1 =	33·8	34 =	29·2
71 =	159·8	35 =	95	0 =	32	35 =	31
70 =	158	34 =	93·2	− 1 =	30·2	36 =	32·8
69 =	156·2	33 =	91·4	2 =	28·4	37 =	34·6
68 =	154·4	32 =	89·6	3 =	26·6	38 =	36·4
67 =	152·6	31 =	87·8	4 =	24·8	39 =	38·2
66 =	150·8	30 =	86	5 =	23	40 =	40
65 =	149						

EXERCISES UPON INORGANIC CHEMISTRY.

1182. During the study of each part of this work, the pupil will receive much benefit from answering a series of questions and exercises, which may be regarded as occupying the place of examination papers. These questions and exercises should be worked out immediately after the study of the substance or doctrine to which they refer, and the length of the examination should necessarily depend upon the age and acquirements of the pupil. When the study of chemistry has so far advanced as to admit of the examination being extended over a division of the treatise, then the questions and exercises should be selected from various parts of the following pages. In all cases the answers should be written out, and should be as full as possible.

1183. EXERCISE I.—INTRODUCTION.

1. Give a definition of the science of chemistry, sufficient to indicate the division of natural science of which it takes cognizance.

2. Name the forces employed by the chemist in his investigations.

3. What is a compound substance, and wherein does it differ from a simple body?

4. Define chemical analysis, and give two examples of the process.

5. How many elementary substances are there? and familiarly

illustrate the mode of their combination to form compound bodies.

6. Define chemical synthesis, and name two substances produced by this process.

7. State the special province of the chemist in the study of nature.

1184. EXERCISE II.—GENERAL PROPERTIES OF MATTER.

1. Describe generally the mode of construction of solids, liquids, and gases.

2. Define the terms—particles, atoms, and molecules.

3. How does the force of cohesion affect solids?

4. Wherein does a liquid differ from a solid in regard to the force of cohesion?

5. State the physical conditions under which gases exist.

6. Does the physical state of a substance as to its solidity, liquidity, or gaseity alter its chemical nature?

1185. EXERCISE III.—WEIGHT—SPECIFIC GRAVITY—ATOMIC WEIGHT.

1. Does chemistry take cognizance of one or several kinds of weight?

2. Define absolute weight, and give examples.

3. What is specific weight or specific gravity, and wherein does it differ from absolute weight?

4. Mention the substance which is taken as unity in the determination of the specific gravity of solids and liquids, and give three examples.

5. Name the body which is regarded as unity in the estimation of the specific gravity of gases, and give three examples.

6. What is atomic weight, and wherein does it differ from absolute weight?

1186. EXERCISE IV.—CHEMICAL AFFINITY.

1. Is chemical affinity exerted among like or unlike particles of matter? Give two examples.

2. Wherein does chemical affinity differ from cohesion and adhesion?

3. What is the difference between a mechanical mixture and a chemical compound?

4. Have the colour and general appearance of a chemical compound any relation to those of its ingredients? Give three examples.

5. When two substances are united by chemical affinity, do they ever change their state of solidity, liquidity, or gaseity? Give three examples.

6. Has the chemical compound different powers of acting upon the animal economy from those of its components? Give two examples.

1187. EXERCISE V.—LAWS OF COMBINING PROPORTION.

1. Do these laws relate to combination by volume or by weight?

2. Does the same compound always consist of the same ingredients? Give three examples.

3. What is the first law of combining proportion? Give three examples.

4. Describe the second law of proportion, and give two examples.

5. Name the third law of proportion, and give two series of examples.

6. Define the fourth law of proportion, and give two examples.

7. State the starting-point of the scale of combining proportions generally used, and contrast it with one other scale.

8. Give the atomic weights of ten of the more commonly occurring elements.

1188. EXERCISE VI.—ATOMIC THEORY.

1. Describe the hypothesis known as the atomic theory.

2. Are the laws of combining proportion dependent upon the existence of the atomic theory?

3. Is the atomic theory in unison with each and all of the laws of combination by weight?

4. Illustrate graphically and atomically the composition of nitric acid and water, and chloride of sodium (common salt).

1189. EXERCISE VII.—CHEMICAL NOMENCLATURE.

1. Give some particulars of the naming of chemical substances in the earlier times.

2. State if there is any system followed in the naming and classification of chemical elements.

3. Define a binary compound; a ternary compound; and a quaternary compound; and give an example of each.

4. When oxygen, chlorine, or sulphur unites with other elements, how may the compound be named?

5. If oxygen combines in more than one proportion with other elements, what prefixes may be used to distinguish between the compounds? Give examples.

6. Under what circumstances is oxygen likely to aid in the formation of an acid compound?

7. State the prefixes and terminations which may be employed in distinguishing between the various acids formed by the union of the same elements. Give examples.

8. When acids unite with bases, describe the mode in which the compound may be named, so as to recognise the particular acid. Give examples.

9. When the same acid unites in various proportions with bases, what prefixes may be used to distinguish such proportions? Give examples.

10. How are quaternary compounds named? Give examples.

1190. EXERCISE VIII.—CHEMICAL NOTATION.

1. Describe the method of chemical notation, especially in regard to the representation of substances possessing the same initial letter.

2. State the meaning and full value of the following symbols: O, H, S, Hg, Ag, and Au.

3. Give the number of atoms and proportions by absolute weight represented by the symbols Fe_2, N_2, C_4, Fe_3, Cl_5, H_{10}.

4. Carbonate of sodium (washing soda) has the symbol, when dry, of $NaCO_3$. State the absolute weight of each of the ingredients.

5. A compound contains 2 parts of hydrogen, 32 parts of sulphur, and 64 parts of oxygen by absolute weight. Write down the formula for the substance.

6. State the order followed in the placing of the symbols of a compound body.

1191. EXERCISE IX.—LAW OF GASEOUS VOLUMES.

1. Mention the connection which subsists between a gas and a vapour.

2. Is any relation observed between the volume of a substance and its combining proportion as contrasted with other elementary bodies?

3. How may gases and vapours be readily measured, and what degree of temperature and pressure of barometer are adopted in the manipulation with gases?

4. What gaseous element is taken as unity of volume, and what space is occupied by a combining proportion of the gases taken in grains?

5. Describe the relation which subsists between the atomic volume, combining proportion by weight, and specific gravity of gaseous substances.

6. Give a tabulated statement of the atomic weight and the atomic volumes of at least four elements.

7. Name the volume occupied by compound gases and vapours, and graphically represent the combining volumes of several elements and compounds side by side.

8. When gases or vapours combine together, is there any alteration in volume? and if so, state the extent to which such alteration has been observed. Give examples.

9. Do the vapours of organic substances follow the same law

of gaseous volumes as the elementary bodies? If so, give examples.

1192. EXERCISE X.—INORGANIC CHEMISTRY AND OXYGEN.

1. Define inorganic chemistry as contrasted with organic chemistry.

2. State the natural sources of oxygen.

3. Describe two processes for the preparation of oxygen, illustrating the changes by symbols.

4. Give a description of the apparatus employed in the reception and storing of oxygen gas.

5. Chlorate of potassium has the symbol $KClO_3$; what are the proportions by absolute weight of each of the ingredients, and how many grains of oxygen will be obtained from 1 lb. or 7000 grains of the salt?

6. Having learned the above, calculate the grains of oxygen into cubic inches (par. 253), then into cubic feet (1728 cubic inches to one cubic foot), and into gallons (6¼ gallons in one cubic foot).

7. Describe the general properties of oxygen, especially in regard to combustion.

8. Name the varieties of oxides, and give two examples of each class.

9. Name the relation which subsists between combustion in air and in oxygen respectively.

10. Has oxygen any influence upon animal life?

1193. EXERCISE XI.—HYDROGEN AND WATER.

1. Name the natural sources of hydrogen.

2. Give three processes for the preparation of hydrogen, and illustrate the chemical changes by symbols.

3. Describe the principal properties of hydrogen, especially in relation to the process of combustion.

4. 100 cubic inches of hydrogen weigh 2·14 grains; what will a cubic foot of hydrogen weigh?

5. The combining weight of zinc is 65·2, and this proportion

in grains, assisted by the sulphuric acid, will decompose 18 grains of water, yielding 2 grains of hydrogen; now, how many grains of hydrogen will one ounce and one pound of zinc respectively yield?

6. Having worked out the above, then proceed: as 2·14 grains of hydrogen measure 100 cubic inches, what volume will the hydrogen liberated from water by one ounce of zinc occupy in cubic inches, and by one pound of zinc in cubic inches, cubic feet, and gallons?

7. State the solubility of hydrogen in 100 cubic inches of water, and calculate the volume of hydrogen dissolved in one cubic foot and in one gallon of water.

8. 100 cubic inches of hydrogen weigh 2·14 grains, and it is required to know the number of grains of water which this amount in burning will produce, and also the number of grains of hydrogen in a cubic foot of the gas, and the weight of the water capable of being formed by the burning of the cubic foot of the gas.

9. Under what circumstances is hydrogen liable to cause an explosion?

10. Explain the principle of the lime-ball light and the oxy-hydrogen blowpipe.

11. Mention the general characters of natural waters; and state wherein the various waters differ from, and agree with, each other.

12. Describe the process which may be followed in the preparation of pure water.

13. One cubic inch of water weighs in air, at 60° F., 252·456 ($252\frac{1}{2}$) grains; what will 100 cubic inches weigh in grains and ounces, and a cubic foot in ounces and pounds avoirdupois?

1194. EXERCISE XII.—NITROGEN.

1. Mention the natural sources of nitrogen.

2. Describe two processes for the preparation of nitrogen, employing symbols in illustration.

3. Calculate the volume of atmospheric air required to yield 100 cubic inches of nitrogen.

4. State the solubility of nitrogen in 100 parts of water at 60° F., and calculate the solubility in one cubic foot and in one gallon of water.

5. Describe the properties of nitrogen in relation to combustion.

6. State generally the remaining characters of nitrogen, when alone, and when combined.

1195. EXERCISE XIII.—THE ATMOSPHERE.

1. Name the principal and minor constituents of atmospheric air, and state the proportions of its principal ingredients.

2. Describe one process for the analysis of the air.

3. How may carbonic acid be recognised in the atmosphere?

4. State how ozone may be detected in the air, and give its principal properties.

5. Mention the principal functions fulfilled by the various gases in the atmosphere.

6. What is the probable height of the atmosphere? and is there any sensible variation in the proportion of the ingredients, either in time or space?

1196. EXERCISE XIV.—DIFFUSION OF GASES.

1. Describe what occurs when gases of different densities, and having no chemical action upon each other, are brought in contact.

2. State the mode of conducting an experiment to illustrate the diffusion of gases.

3. Adapt the doctrine of the diffusion of gases to the atmosphere, and give the relative densities of the gases present therein.

4. State the relative diffusibility of hydrogen and oxygen, and of hydrogen and air, and define the law of diffusion.

1197. EXERCISE XV.—NITRIC ACID.

1. Mention the difference between nitric anhydride and ordinary nitric acid. Give symbols.

2. What are the natural sources of nitric acid?

3. Give two processes for the preparation of nitric acid, illustrating the changes by symbols.

4. State the percentage of nitric anhydride in the ordinary commercial nitric acid, and in the stronger fuming acid, and give the symbols and densities of both acids.

5. Calculate the amount of ordinary commercial acid capable of being yielded by 100 parts (say ounces) of nitrate of potassium. Thus, the symbol and combining weight of nitrate of potassium are KNO_3 = K 39, N 14, and O 48, altogether 101, and the symbol and combining weight of the commercial acid are $2HNO_3, 3H_2O = 180$, divided by 2 (as there are two parts of HNO_3 present in the latter) = 90. Therefore,

$$101 : 90 : : 100 : = \text{parts of commercial acid.}$$

6. Repeat the above calculations, but start with 100 parts of nitrate of sodium, $NaNO_3$. Add up combining proportion of $NaNO_3$, and then proceed with calculations.

7. Give the general properties and tests for nitric acid.

1198. EXERCISE XVI.—OTHER OXIDES OF NITROGEN.

1. Write down the names and symbols of all the oxides of nitrogen.

2. Describe the process for the preparation of nitrous oxide, using symbols.

3. Give the principal properties of the gas; viz., its density, solubility in water, relation to combustion, and action on the animal system.

4. 100 cubic inches of the nitrous oxide weigh 47·29 grains; calculate what one cubic foot will weigh; and having reference to the diagram at par. 339, calculate the amount of nitrate of ammonium required to yield a cubic foot of the gas.

5. Give one process for the preparation of nitric oxide, illustrating the changes by symbols.

6. What relation does nitric oxide bear to combustion, and how does the gas act when it meets with a gaseous mixture containing more or less oxygen?

7. How may nitrous acid be prepared?

8. Describe the process for the preparation of hyponitric acid, and give its properties.

1199. EXERCISE XVII.—CARBON.

1. Name the natural and artificial varieties of carbon.

2. How are the artificial forms of carbon prepared?

3. What influence have the various kinds of carbon upon coloured liquids?

4. Does the carbon act in any way upon gases?

5. What change occurs when carbon is raised sufficiently in temperature to burn?

1200. EXERCISE XVIII.—CARBONIC ACID.

1. Name the natural sources of carbonic acid.

2. Describe the synthetic process for the preparation of carbonic acid, using symbols.

3. Give an analytic method of liberating the carbonic acid, illustrating the changes by symbols.

4. 100 cubic inches of oxygen weigh 34·203 grains, and taking advantage of the information at par. 371, it is required to know what weight the 100 cubic inches will possess when the whole of the oxygen has combined with the carbon and formed carbonic acid.

5. About 47 grains of carbonic acid measure 100 cubic inches, and a combining proportion in grains of marble, which is the carbonate of calcium, $CaCO_3$ (CaO,CO_2) = 100, can yield, on the addition of acid, 44 grains of carbonic acid. Calculate the number of cubic inches of the gas capable of being yielded by 100 grains of the marble, and also by one pound or 7000 grains.

6. Having learned the above, consider what other calculations are necessary, and state the weight of marble required to yield a cubic foot of carbonic acid.

7. Mention the properties of carbonic acid in relation to combustion.

8. How does carbonic acid act upon animal life?

9. Is carbonic acid ever evolved naturally, or otherwise, in sufficient quantity to influence the life of animals? If so, state the circumstances.

1201. EXERCISE XIX.—CARBONIC OXIDE.

1. Describe two processes for the preparation of carbonic oxide from carbonic acid, illustrating each by symbols.

2. 100 cubic inches of carbonic oxide weigh 30·21 grains, and 100 cubic inches of carbonic acid weigh 47·303 grains. Give the calculations which prove the correspondence of these figures.

3. Explain the preparation of carbonic oxide from oxalic acid, using symbols.

4. Name the principal properties of carbonic oxide, especially in relation to combustion.

5. Does carbonic oxide possess any influence on the respiration of animals?

1202. EXERCISE XX.—COMPOUNDS OF CARBON AND HYDROGEN.

1. Give the names and symbols of the compounds of carbon and hydrogen which may be regarded as belonging to inorganic chemistry.

2. Describe a process for the preparation of heavy carburetted hydrogen, using symbols.

3. Mention the properties of olefiant gas in relation to combustion.

4. How does chlorine act upon olefiant gas?

5. Do any of the carburetted hydrogens occur naturally? If so, where?

6. What process may be followed in the preparation of light carburetted hydrogen?

7. Describe the properties of light carburetted hydrogen.

8. Name the principal and minor constituents of coal-gas.

9. Give a general statement of the manufacture and purification of coal-gas.

1203. EXERCISE XXI.—THE DAVY LAMP, STRUCTURE OF FLAME, AND THE BLOWPIPE.

1. Explain the principle involved in the construction of the Davy lamp.

2. Under what circumstances is coal-gas liable to explode?

3. When an explosion does occur in a coal-mine, what gases are produced, and what properties do they possess?

4. Name the several areas of combustion in a coal-gas or candle flame.

5. Explain the theory of the production of luminous flame from the combustion of an ordinary coal-gas flame.

6. How is the Bunsen lamp constructed, and wherein does the combustion of gas from it differ in its combustion from an ordinary gas jet?

7. Name the different blowpipe flames, and state their positions.

8. What chemical changes are brought about in the different blowpipe flames? Give examples.

1204. EXERCISE XXII.—BORON AND BORACIC ACID.

1. Give the natural sources of boron.

2. Describe one process for the preparation of the element.

3. State the various conditions in which boron can be obtained.

4. Give the symbol for boracic acid, and illustrate symbolically the process of its preparation.

5. How may boracic acid be distinguished from other substances?

6. Name the compound of boracic acid employed largely in the arts, and state its uses.

1205. EXERCISE XXIII.—SILICON AND SILICIC ACID.

1. In what state does silicon occur in nature?

2. Describe the various conditions in which silicon can be procured.

3. Give a process for the preparation of silicic acid or silica in a gelatinous form, and subsequently in a finely divided state.

4. Name the principal properties of silica, especially in regard to high temperatures.

5. State the principal components of glass.

1206. EXERCISE XXIV.—SULPHUR.

1. Name the natural sources of sulphur, either free or in combination.

2. In what state is sulphur met with in commerce?

3. Give the general properties of sulphur, especially in regard to the solvents of the substance.

4. What changes occur when sulphur is heated, and how far are its ordinary properties modified on the application of heat?

5. Does sulphur form any compound with carbon? and if so, what are the symbol and nature of the compound?

1207. EXERCISE XXV.—SULPHUROUS ACID.

1. Describe the mode of the formation of sulphurous acid by synthesis, employing symbols.

2. Give two processes for the preparation of sulphurous acid by analysis, illustrating the changes by symbols.

3. Name the principal properties of sulphurous acid, especially in regard to solubility in water and relation to combustion.

4. Observing the specific gravities of sulphurous acid, oxygen, and hydrogen, and the respective weights of 100 cubic inches of each gas, it is required to calculate the capacity in cubic inches of 100 grains of each of the gases.

5. How does sulphurous acid affect coloured woollen and

silken materials? and in what conditions may the acid be employed?

6. Has sulphurous acid any influence on the putrefaction of organic substances? and if so, can the acid be employed otherwise than as gas?

7. Name any compound which contains sulphurous acid, and give its symbol and properties.

1208. EXERCISE XXVI.—SULPHURIC ACID.

1. Describe the process for the preparation of Nordhausen sulphuric acid, using symbols.

2. Give the symbol, strength, and uses of the Nordhausen acid.

3. How is sulphuric anhydride prepared, and what are its general properties?

4. Give the outlines of the manufacture of ordinary sulphuric acid, or English oil of vitriol, using symbols; and particularly refer to the densities of the acid at various stages.

5. Observing the atomic weight of sulphur, and the combining proportion of oil of vitriol, it is required to calculate the weight of sulphuric acid obtainable from 100 lbs. of sulphur.

6. Having worked out the above, and taking the mean specific gravity of oil of vitriol to be 1846, whilst water is 1000, calculate the number of gallons of acid obtained from the 100 lbs. of sulphur (the gallon of water weighs 10 lbs.).

7. Give the general properties of ordinary sulphuric acid, especially its action upon other substances.

8. How may sulphuric acid or any of its compounds be distinguished by chemical tests?

9. Is there any other oxide of sulphur besides SO_2 and SO_3, which forms one or more important compounds? If so, give the name, symbol, and uses.

1209. EXERCISE XXVII.—HYDROSULPHURIC ACID.

1. Explain two processes for the preparation of hydrosulphuric acid gas, illustrating both by symbols.

2. Mention the general properties of the acid gas; give its solubility in water, and state if its solution ever occurs naturally.

3. What is the action of the gas upon metals and metallic salts?

4. How is the solution of the gas in water prepared, and what properties does it exhibit when brought in contact with metallic salts?

5. Has hydrosulphuric acid ever been liquefied? and if so, under what circumstances?

6. Give the method of preparing the persulphide of hydrogen, state wherein it differs in composition from the hydrosulphuric acid, and mention its properties.

1210. EXERCISE XXVIII.—SELENIUM AND ITS COMPOUNDS.

1. Where is selenium found native, and what are the general characters of the element?

2. Name the compounds which selenium forms, give the symbols for such, and state if any other element forms analogous compounds. Place the names and symbols of the respective elements and their compounds side by side.

1211. EXERCISE XXIX.—PHOSPHORUS.

1. Give the natural sources of phosphorus.

2. Describe the process generally followed in the preparation of phosphorus.

3. State the general properties of phosphorus, especially in regard to luminosity.

4. How does phosphorus conduct itself when subjected to the action of heat, more or less intense?

5. How is red or amorphous phosphorus prepared, and what other kinds of phosphorus are there?

6. State the difference in the properties of ordinary and amorphous phosphorus, especially in regard to their solution in liquids, and their action upon animal life.

1212. EXERCISE XXX.—COMPOUNDS OF PHOSPHORUS WITH OXYGEN.

1. Name the compounds of phosphorus and oxygen, and give their symbols. Give full calculations in making up their combining numbers.

2. Having regard to the above, calculate the percentage composition of each of the compounds.

3. How is hypophosphorous acid prepared? what is its more commonly occurring compound? and state its more striking property.

4. Under what circumstances is phosphorous acid prepared by the combustion of phosphorus?

5. Can the phosphorous acid be obtained by any other process? If so, describe the plan of operating.

6. State how phosphoric acid can be prepared synthetically, and calculate the weight of phosphoric anhydride capable of being obtained from 100 grains of phosphorus.

7. Describe the properties of phosphoric acid.

8. Make special reference to the power which phosphoric acid possesses of combining with bases.

1213. EXERCISE XXXI.—PHOSPHURETTED HYDROGEN.

1. Describe the mode of the preparation of phosphuretted hydrogen, referring specially to the precautions required to be observed.

2. State the most striking property of the gas, and mention what chemical changes occur during its combustion.

3. Is there any other compound of phosphorus and hydrogen than PH_3? If so, give its symbol, and state its properties.

4. Does phosphuretted hydrogen ever enter into union with substances? If so, give an example.

1214. EXERCISE XXXII.—CHLORINE.

1. What other elementary bodies form a family group with chlorine, and what name is applied to the class of bodies?

2. Give the natural sources of chlorine.

3. Describe the mode of preparation of chlorine, illustrating the changes by symbols.

4. Name the general properties of chlorine as to colour, density, and solubility in water.

5. Does chlorine unite readily with any of the metals? If so, give examples by name and symbols.

6. Explain the reaction which takes place when chlorine and hydrogen are brought in contact; mention the circumstances under which they unite together, and name the product formed.

7. State the principal points relating to the influence of chlorine upon combustibles.

8. Name a few colouring substances which are bleached by chlorine.

9. How is bleaching-powder prepared? what is its composition and symbol, and state how the solution may be obtained?

10. Mention the stages of the process usually followed in the bleaching of linen and cotton fabrics.

11. How may bleaching-powder be employed in producing patterns upon coloured cloth?

12. State particularly the influence which chlorine exerts upon noxious gases; and mention how the chlorine may be obtained for this purpose.

1215. EXERCISE XXXIII.—HYDROCHLORIC ACID.

1. Give the earlier names employed to designate this acid.

2. Describe the process for the preparation of the gaseous acid, using symbols in full.

3. State the principal properties of the gas, especially in relation to density, solubility in water, and influence upon combustion.

4. Explain how the solution of the gas in water, commercially known as hydrochloric acid, may be procured.

5. What is the density of the strongest solution of hydrochloric acid, and what percentage of real acid is present therein.

6. Observing the combining weight of chloride of sodium,

and that of hydrochloric acid, calculate the amount of real acid capable of being yielded by 100 lbs. of the chloride of sodium, and thereafter calculate the weight of commercial acid (42 per cent. strength) which this will amount to.

7. Having learned the above, and knowing that the specific gravity of the commercial acid is 1·210, it is required to calculate further how many gallons of acid are capable of being procured from the 100 lbs. of common salt. (Water, specific gravity = 1·000, and 10 lbs. to the gallon.)

8. Explain the reaction which occurs when hydrochloric acid is brought in contact with a base such as potash, K_2O.

9. Name the tests for hydrochloric acid, both pure and impure.

10. How is aqua regia prepared, and what is it employed for?

1216. EXERCISE XXXIV.—OXIDES OF CHLORINE.

1. Name the oxides of chlorine, give the symbols, and calculate the atomic proportions.

2. How is hypochlorous acid prepared? what are its properties, and what relation subsists between it and hypochlorous anhydride?

3. Give some particulars regarding chlorous anhydride and chlorous acid.

4. How is hypochloric acid prepared, and what are its most striking properties?

5. Describe the process for the preparation of chloric acid, and illustrate the changes by symbols.

6. Give the name and symbol of the principal compound of chloric acid, and mention its properties and uses.

7. How is perchloric acid prepared, and what are its properties?

8. State the process for the preparation of terchloride of nitrogen, and give its principal characters.

1217. EXERCISE XXXV.—IODINE AND ITS COMPOUNDS.

1. Name the natural sources of iodine.

2. Describe the process of the manufacture of iodine, using symbols.

3. State the properties of iodine, especially in regard to the action of heat.

4. The vapour of iodine has the specific gravity of 8·716 (air = 1·000), and 100 cubic inches of air weigh 31·074 grains; it is required to know the weight of 100 cubic inches of the vapour of iodine.

5. What are the principal tests for iodine?

6. How is hydriodic acid prepared? and mention some of the compounds it forms.

7. Explain how the starch test may be applied to iodides, and give any other tests which are characteristic.

8. Describe the preparation of iodic acid, and mention its properties.

9. How is the iodide of nitrogen prepared? Give its symbol, and state its most striking property.

1218. EXERCISE XXXVI.—BROMINE AND ITS COMPOUNDS.

1. Give the natural sources of bromine.

2. Explain how it may be prepared from spring or sea water, using symbols.

3. State the general properties of bromine.

4. Under what circumstances does it pass into vapour, and what are the principal characters of the vapour?

5. The specific gravity of the vapour of bromine is 5·540 (air = 1·000), and having ascertained the weight of 100 cubic inches of air, it is required to know the weight of 100 cubic inches of bromine vapour.

6. Give the names and symbols for the principal compounds of bromine.

1219. EXERCISE XXXVII.—FLUORINE AND ITS COMPOUNDS.

1. Where does fluorine occur native?

2. State what is known about fluorine as an element.

3. How is hydrofluoric acid prepared, and what properties does it possess?

4. Give the formula for hydrofluosilicic acid, and state the mode of its preparation.

1220. EXERCISE XXXVIII.—METALLIC ELEMENTS—GENERAL OBSERVATIONS, PROPERTIES, AND RELATIONS.

1. Give the number of the metals at present known, and state the properties which distinguish a metal from a non-metal.

2. In what conditions are the principal metals found in nature?

3. Do the densities of the metals vary much? Give examples.

4. State the various shades of colour which are characteristic of different metals.

5. Have the colours of the metals any power of influencing the tints of their compounds or salts?

6. Do any of the metals exhibit liquidity at ordinary temperatures?

7. What crystalline forms do the metals generally assume?

8. Describe the influence of heat upon the plasticity and fusion of the metals.

9. Define malleability and ductility, and give examples.

10. Mention the general relations of metals to oxygen, and relatively to the process of combustion.

11. Name some important points connected with metallic oxides.

12. State the leading features of the sulphides of the metals.

13. Mention the divisions of the metals into classes which are found of service in the grouping of the metals.

1221. EXERCISE XXXIX.—POTASSIUM AND ITS COMPOUNDS.

1. Name the metals which are similar to and are associated with potassium.

2. Under what circumstances does potassium occur native?

3. How is the metal prepared, and what are its properties?

4. Describe the process for the preparation of caustic potass,

and state its properties, especially in reference to its action on colouring agents.

5. Give some particulars regarding the carbonates of potassium.

6. State the composition, properties, and uses of nitrate of potassium, and calculate the percentage composition of the salt.

7. Name some other compounds of potassium, and give their symbols.

8. What are the tests for the compounds of potassium?

1222. EXERCISE XL.—SODIUM AND ITS COMPOUNDS.

1. What are the natural sources of sodium?

2. How may the metal be prepared, and what are its properties?

3. Describe the preparation of hydrate of caustic soda, and give its symbol and properties.

4. State the common names and symbol for nitrate of sodium, and mention its uses.

5. Give the sources of carbonate of sodium, describe the mode of its manufacture from common salt, and give its symbol when crystallised.

6. Add up the combining proportions of chloride of sodium and of crystallised carbonate of sodium respectively, and then calculate how much of the latter should be obtained from 100 tons of the former.

7. Also calculate how much sulphuric acid, of the strength of oil of vitriol, would be required to decompose the 100 tons of chloride of sodium.

8. Give the tests for the compounds of sodium.

1223. EXERCISE XLI.—AMMONIUM AND ITS COMPOUNDS.

1. What properties does ammonium possess in common with the metals of the alkalies?

2. Describe the commercial sources of ammonia.

3. Give the properties of gaseous ammonia, especially its action upon colouring agents, and its solubility in water.

4. Name some of the principal salts of ammonium, and give their symbols.

5. Explain the mode of construction of several of the salts, so as to illustrate the analogy of the ammonium salts to the corresponding compounds of potassium or sodium.

6. Describe the process for preparing the amalgam of the hypothetical compound metal ammonium.

7. State the tests for compounds of ammonium.

1224. EXERCISE XLII.—CALCIUM AND MAGNESIUM.

1. How is quicklime prepared, and what are its properties?

2. Add up the atomic weight of quicklime, CaO, and of slaked lime, CaO,H_2O, and calculate what weight of slaked lime will be obtained from 100 pounds of quicklime.

3. Explain the theory of the use of slaked lime in the compounding of mortar.

4. Give the chemical names, symbols, and principal properties of chalk, gypsum, and bone earth.

5. Describe the process for preparing magnesium, and state its principal properties.

6. Give the formula for dolomite, and adding up the combining proportion of its constituents, calculate the percentage proportion of the two leading components.

7. How is sulphate of magnesium prepared, and what is its formula and common name?

1225. EXERCISE XLIII.—BARIUM AND STRONTIUM.

1. In what state is barium found native?

2. Name the principal salts of barium, and give the symbols for such.

3. What are the natural sources of strontium?

4. Give the names and symbols of the principal compounds, and state if any are used in the arts.

5. Name the various tests which may be employed to distinguish between the compounds of the metals of the alkaline earths.

1226. EXERCISE XLIV.—ALUMINUM AND CHROMIUM.

1. Describe the manufacture, properties, and uses of the metal aluminum.
2. Give the process for the preparation of alum, and illustrate its composition by symbols.
3. Mention the properties of alum, especially in relation to colouring matters.
4. Name the principal points connected with clay and porcelain.
5. Give the tests for aluminum in combination.
6. In what condition is chromium found native?
7. Describe the preparation of bichromate of potassium.
8. Name the oxides of chromium, and state how they may be obtained.
9. Give the names and symbols for some other compounds of chromium.

1227. EXERCISE XLV.—ZINC AND ITS COMPOUNDS.

1. Name the ores of zinc, and describe the process of extracting the metal.
2. Give the properties of the metal, especially in relation to the changes occurring on the application of heat.
3. State the commercial and chemical uses of the metal.
4. Name the principal compounds of zinc, and give their symbols.
5. What are the tests for the salts of zinc?

1228. EXERCISE XLVI.—IRON AND ITS COMPOUNDS.

1. Give the name and symbols of the principal ores of iron.
2. Describe the process of smelting the iron ore, and preparing the cast-iron.
3. What ingredients are present in cast-iron besides the metal itself?
4. Explain the mode of refining the cast-iron, and converting it into malleable iron.

5. Wherein does the malleable iron differ from the cast iron in physical and chemical properties?

6. How is steel prepared from malleable iron?

7. What are the principal properties of steel?

8. Name the oxides of iron, and give the symbols for such; state if any of these occur native, or are met with commercially.

9. Name the principal salts of iron, and give the symbols of such.

10. State the tests for the salts of iron.

1229. EXERCISE XLVII.—MANGANESE, COBALT, AND NICKEL.

1. Give the names and symbols for the oxides of manganese, and state if any of these occur native.

2. Is manganese or its compounds employed in the arts and manufactures?

3. Name the principal salt of manganese.

4. Give the tests for the compounds of manganese.

5. Mention the minerals which contain cobalt and nickel.

6. State the uses of those metals and their compounds in the arts.

7. How are the salts of cobalt and nickel recognised?

1230. EXERCISE XLVIII.—COPPER AND ITS COMPOUNDS.

1. What are the principal ores of copper? Give symbols, and calculate the percentage of copper in each ore, assuming no impurity to be present.

2. State the properties of copper.

3. Give the names and symbols of the oxides, and state how these may be obtained.

4. Name the principal salts of copper, and give the symbols. Calculate the perçentage composition of at least one salt.

5. What are the tests for the salts of copper.

1231. EXERCISE XLIX.—LEAD AND ITS COMPOUNDS.

1. Name the principal ore of lead, and state how the metal may be extracted therefrom.

2. Give the general properties of lead, especially in regard to the action of water thereon.

3. Name the oxides of lead, give the symbols for such, and state how they may be prepared.

4. Mention the principal salts of lead, give their symbols, and state their properties and uses. Calculate the percentage composition of one of the salts.

5. Name the tests for lead.

1232. EXERCISE L.—SILVER AND ITS COMPOUNDS.

1. What are the ores of silver?

2. Detail a process for procuring pure silver.

3. Mention the properties of the metal.

4. How is nitrate of silver prepared, and how much of the salt ought to be obtained by the action of nitric acid on 100 grains of the metal.

5. Give the test for silver and its compounds.

1233. EXERCISE LI.—MERCURY AND ITS COMPOUNDS.

1. State the principal ore of mercury, and how the metal may be extracted therefrom.

2. Give the properties of metallic mercury.

3. Name the oxides of mercury, give their symbols, and state how they may be prepared.

4. How is corrosive sublimate prepared? and calculate the weight of the salt capable of being made from 100 grains of metallic mercury and sulphate of mercury respectively.

5. State how the preparation of calomel differs from that of corrosive sublimate, and calculate the weight of this salt which 100 grains of metallic mercury and of sulphate of mercury respectively will yield.

6. Calculate the percentage composition of the two chlorides of mercury, and place such side by side.

7. Name the principal properties of calomel and corrosive

sublimate, particularly referring to the differences between the two salts.

8. Give the principal tests for the salts of mercury.

1234. EXERCISE LII.—BISMUTH AND CADMIUM.

1. Name the properties of bismuth.
2. Mention the compounds, and give the symbols for such.
3. Where is cadmium found native?
4. State the characters of the metal cadmium.

1235. EXERCISE LIII.—GOLD AND PLATINUM.

1. In what condition is gold found native?
2. Give the general properties of the metal.
3. What solution of gold is likely to be met with, and how may it be recognised by tests?
4. In what state does platinum occur native?
5. Name the properties of the metal, and state its chemical and commercial uses.
6. How is the solution of the perchloride obtained, and what test will recognise it?
7. How are spongy platinum, and platinum black, prepared?

1236. EXERCISE LIV.—TIN AND ANTIMONY.

1. What is the leading ore of tin?
2. Give the properties of tin.
3. Name its principal salts and their uses.
4. State the tests for the compounds of tin.
5. In what state does antimony occur native, and how is it extracted from its ore?
6. Describe the properties of metallic antimony.
7. Give the names and symbols of the oxides of the metal, and state how they are formed.
8. How is tartar emetic prepared, and what is its composition?
9. State the tests for antimony and its compounds.

1237. EXERCISE LV.—ARSENIC AND ITS COMPOUNDS.

1. State the general properties of the metal.

2. Name the oxides and give their symbols.

3. Give the characters of arsenious acid, both on the application of heat and also by the liquid tests.

4. Describe Reinsch's process for the detection of arsenical compounds.

5. Explain Marsh's process.

6. Give the details of Berzelius's method for detecting the compounds of arsenic.

7. How is arsenic acid prepared, and what are its properties?

8. Name some of the rarer metals, and give their symbols.

1238. EXERCISE LVI.—ATOMICITY OF THE ELEMENTS.

1. Give a definition of a chemical atom, and state the terms employed to designate the proportions in which atoms combine together. Give examples.

2. What is meant by a molecule of a substance? and give examples of the molecular weights of a number of elements, such as H, O, N, Cl, K, Na, Fe, and Hg.

3. What volume do the atom and molecule of an element respectively occupy as gas or vapour? Give examples.

4. Define the term equivalent, and give the name, symbols, and combining equivalents of three elements.

5. What is meant by the term monad as applied to an element? Give examples.

6. What is a dyad, and wherein does it differ from a monad? Give examples.

7. Define a triad, and give examples.

8. State the difference between a tetrad and each of the previous classes. Give examples.

9. What means can be adopted to indicate by the symbols the relative equivalent power of the elements?

1239. EXERCISE LVII.—CLASSIFICATION OF SUBSTANCES ACCORDING TO ATOMICITY.

1. Give the number of the monad elements; name the principal member of the group, and state the synonyms employed to designate the group of elements.

2. Give the same information regarding the dyad elements.

3. Proceed to refer to the triad elements in a similar manner.

4. Carry out the exercise by including the tetrad elements.

5. When equal volumes of gases or vapours combine together, do they always form the same volume of the compound as the mixed gases did before combining?

6. Name the element which forms the standard of unity in referring to the combination of the elements by volume, and state the different classes into which the elements may be arranged.

7. Define the monohydric group of elements, and give examples.

8. Define the dihydric group of elements, and give examples.

9. Define the trihydric group of elements, and give examples.

10. Define the tetrahydric group of elements, and give examples.

11. Can the hydrogen be replaced by other substances, and the character or type of the class be still retained? If so, give examples.

1240. EXERCISE LVIII.—THEORY OF THE CONSTITUTION OF ACIDS, BASES, AND SALTS.

1. Name the two groups of acids recently supposed to exist. Give examples.

2. Can these two groups be classified as one? and if so, name the group, and illustrate symbolically the manner in which the members of both groups can be associated together.

3. Mention the connection which subsists between one or

more atoms of water, and different acid substances, and give examples.

4. Give a definition of a base, and name examples.

5. What is a basyle? Give examples.

6. Wherein does a sulphur base differ from an oxygen base?

7. How are salts formed? Give illustrations of several classes of salts.

8. Do the monad and dyad elements respectively enter into the constitution of acids? And if so, illustrate by symbols the relative power of each.

9. Explain the connection between the various classes of salts by the binary theory.

1241. EXERCISE LIX.—CRYSTALLISATION AND CRYSTALLOGRAPHY.

1. Name the various processes by means of which crystallisation may be brought about.

2. Do the same substances always crystallise in the same forms? and if not, are these different forms generally connected together?

3. Name the various crystalline systems.

4. Explain in writing and by drawing the typical forms of the crystalline systems.

5. Give examples of substances belonging to the principal crystallographic systems.

6. Define the term dimorphous, and give examples of dimorphism.

7. Explain the word isomorphous, and give examples of isomorphism.

1242. EXERCISE LX.—STRENGTHS OF ACID AND ALKALINE SOLUTIONS.

The tables (pars. 1159 to 1164) give the relative and actual strengths of solutions of acids and alkalies possessing different specific gravities or densities, and they are intended as a guide in calculating the proportion of acid or alkali in a solution of a given specific gravity, with that of a second solution of a different specific gravity. The admixture of water to some of the stronger solutions, for the purpose of obtaining a weaker solution, does not always yield the latter of the exact strength required, as certain contractions and expansions result from the union of the water with the stronger solution; but in the course of this exercise, we may regard the variations thus brought about as of no practical importance.

1. Fuming nitric acid has the specific gravity of 1·500, and it is desired to add water sufficient to convert 100 ounces by measure of fuming acid into ordinary commercial nitric acid of the specific gravity 1·424. Calculate the amount of water required, and state the volume of commercial acid which will be obtained.

2. Having calculated the above, then proceed to convert the acid of 1·424 specific gravity into acid containing 40 per cent. of anhydrous nitric acid, and give the volume of the latter acid.

3. 20 ounces by measure of fuming acid are required to carry out a certain chemical change, and the weaker acid will do so far as strength is concerned, but it is required to know the volume of the 1·424 acid which will replace the 20 ounces of the stronger acid.

4. The strong solution of ammonia in water, known as *aqua ammoniæ fortissima* contains 36 per cent. of ammonia, and it is required to add water sufficient to convert 10 ounces by measure of this liquid into a solution containing only 12 per cent. of ammonia. Calculate how much water is required, and give the volume of the weaker ammonia solution thus obtained.

5. Reverse Question 4, and calculate how many ounces of the stronger ammonia would be required to do the same chemical duty as 40 ounces of the weaker ammonia (containing only 12 per cent. of ammonia).

6. What is the percentage of oil of vitriol in sulphuric acid of specific gravity 1·400, 1·500, 1·600, and 1·700 respectively?

7. Resolve 10 gallons of oil of vitriol into acid of specific gravity 1·700, 1·600, 1·500, and 1·400 respectively, and give the quantities obtained of each.

8. Work out similar exercises with solutions of hydrochloric acid (par. 1162), potass (par. 1163), and soda (par. 1164).

1243. EXERCISE LXI.—THE GASES AND VAPOURS.

The table (1165) will be found of service in calculating the specific gravity or density of compound gases and vapours from that of their components. Thus one volume of hydrogen, weighing 0·0692, and one volume of chlorine, weighing 2·470, form two volumes of hydrochloric acid, so that 0·0692 + 2·470 = 2·5392, and the latter divided by 2, gives 1·269 as the calculated specific gravity of hydrochloric acid.

1. One volume of hydrogen and one volume of iodine vapour are contained in two volumes of hydriodic acid vapour. Calculate the specific gravity of the latter.

2. Calculate also the specific gravity of hydrobromic acid vapour.

3. Two volumes of hydrogen and one volume of oxygen form two volumes of steam. What is the calculated specific gravity of steam?

4. Three volumes of hydrogen and one volume of nitrogen are contained in two volumes of gaseous ammonia. What is the calculated specific gravity of the latter?

1244. EXERCISE LXII.—THE METALS.

SPECIFIC GRAVITY, FUSIBILITY, MALLEABILITY, DUCTILITY, AND TENACITY.

The specific gravity of a metal is its relative weight as contrasted with water, and any given volume of water which would weigh 1, the same volume of platinum would weigh 21·53; of lead, 11·36; of iron, 7·84; of magnesium, 1·74; and of potassium, 0·865 (less than water).

1. A cubic inch of water weighs 252·456 grains, what will a cubic inch of platinum weigh?

2. Make similar calculations for a cubic inch of zinc, iron, copper, silver, and lead.

3. An article made of iron weighs 20 ounces, what would it weigh if constructed of gold?

4. Give the fusing points of six of the more common metals.

5. Define the term malleability, and state the order of malleability of the more commonly occurring metals.

6. What is ductility? and how do the metals arrange themselves as to the property of ductility?

7. Give a definition of tenacity, and mention the order in which the metals exhibit this property.

1245. EXERCISE LXIII.—METRICAL AND BRITISH MEASURES.

Much importance is now attached to the relative value of the French or metrical, and the common British measures, especially those of length, capacity, and weight; and as it appears probable that the adoption of the metrical system in this country is a mere question of time, it is advisable that a certain amount of knowledge of the relative values of the different weights and measures should be acquired. Already the metrical system is employed by many scientific chemists, and the use of it is now legalised in Britain.

1. Give the length of a metre in British inches.

2. How many decimetres, centimetres, and millimetres are contained in a metre?

3. Name the metrical measures of length which are higher than a metre.

4. State the capacity of a litre in cubic inches.

5. Calculate the number of litres in a gallon.

6. Name the measures of capacity, in the metrical system, below and above a litre, and their relative value to the litre.

7. What is the value of a gramme in grains?

8. Calculate the number of grammes in 1000 grains.

9. Name the metrical weights below and above a gramme, and their relative value to the gramme.

10. How many grains are there in an ounce and a pound avoirdupois?

11. Give the number of grains in an ounce, a pint, and a gallon of water.

12. How many ounces and pints are there in an imperial gallon? and calculate the number of cubic inches in a gallon.

1246. EXERCISE LXIV.—THERMOMETRIC EQUIVALENTS.

The thermometer generally employed in this country is that of Fahrenheit, which commences with 32° as the freezing point of water, and gives 212° as its boiling point, thereby placing 180° or divisions between the freezing and the boiling points of water. The Centigrade thermometer employed in many parts of the Continent, and coming into use in this country, starts with the freezing point of water as zero, or 0°, and gives the boiling point as 100°, and consequently divides the space between the freezing and boiling points of water into 100° or divisions. As the Centigrade scale is often given in scientific treatises, we may have occasion to consult the table (par. 1181), and it is also important to be able to calculate the degrees of either of the systems into that of the other. The principle on which this may be done will be observed from the following explanation. The 180° between the freezing and the boiling points of water on the Fahr. scale are only equal to the corresponding 100° on the Cent. scale; consequently, in the same proportion, 9° Fahr. are equal to 5° Cent. And further, there is the additional 32° which the scale of Fahr. starts with, and which must be deducted from the degree of temperature when Fahr. is being resolved into Cent., and be added when Cent. is being passed into the Fahr. scale. The rule of working is, when Fahr. is to be resolved into Cent., deduct the 32°, multiply the remainder by 5, and then divide by 9; and when Cent. is to be passed into Fahr., multiply by 9, divide by 5, and then add 32°. The pupil should calculate in full the following exercises, and he can thereafter consult the table (par. 1181) in order to observe the accuracy of the answers.

1. Calculate 200° Fahr. into Cent.
2. Calculate 87° Cent. into Fahr.
3. Calculate 70° Fahr. into Cent.
4. Calculate 37° Cent. into Fahr.
5. Consult the previous parts of the treatise, and calculate the following temperatures, which are given in Fahr., into the Cent. scale: The boiling point of fuming nitric acid; the boiling point of commercial nitric acid; the fusing point of sulphur; the boiling point of sulphuric acid; the fusing point of phosphorus; and the fusing point of the metals Sn, Pb, Zn, Ag, Cu, Au, and cast iron.

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